BBC

HOW NASA'S NEXT SPACE TELESCOPE CHANGES EVERYTHING

Science Focus

EUREKA!

IDEAS YOU NEED TO UNDERSTAND IN 2022

AUGMENTED INTELLIGENCE
CANCER VACCINES
BEATING BURNOUT
LUNAR SPACE STATION
ALIENS IN OUR SOLAR SYSTEM
A HUMAN RIGHT TO NATURE

SF
SCIENCEFOCUS.COM
>09
#372 USA $11.50 CAN $13.99 AUS $13.50 NZ $18.90 UK $5.50

IN THIS ISSUE

Michael Mosley
Why some hate jogging (and others love it)

Boba Fett
Could you survive being frozen like Han Solo?

Mammoths
The mind-blowing graveyard found in the UK

ROYAL SOCIETY OF CHEMISTRY

BECOME A **MEMBER**

Resources. Support. Connections.

Make a greater impact with the RSC.

Realise your full potential. Join us today.

rsc.li/membership

ADVANCING CHEMISTRY. TOGETHER.

FROM THE EDITOR

All being well, by the time you read this, the James Webb Space Telescope (JWST) will have launched (finally) and should be on its way to the second Lagrange point, a spot 1.5 million kilometres away from Earth where the gravity from the Sun and Earth will lock the satellite into a fixed position between the two. With this feat, the JWST will be able to peer back at the seeds of some of the first stars in the Universe being sown. It could rewrite our origin story.

It's the most ambitious project NASA has ever undertaken that doesn't involve human lives. It's also one of the most expensive. The telescope's tab is floating around the $10bn mark – over three times the price of the Perseverance mission that's currently exploring Mars, and 10 times the cost of the Rosetta mission that explored a comet. To make matters worse, this is one of the most delicate, sensitive pieces of equipment ever built. A tiny mote of dust in the wrong place could derail the mission. And it's got to launch into space, then deploy and unpack its massive sunshield and solar panels without a hitch. My guess is that there are precious few fingernails to chew at NASA right now.

You can find out about the plans for JWST on p25. But it's not the only big idea we're tackling this issue – there are plenty more developments in the worlds of science and technology that are set to make splashes in 2022, from space stations (p50) and the right to a clean environment (p60), to augmented intelligence (p72) and cancer vaccines (p44). Get the lowdown on these topics and you'll have a leg-up on the ideas that are likely to shape the year ahead.

Daniel Bennett

Daniel Bennett, Editor

WANT MORE? FOLLOW **SCIENCEFOCUS** ON FACEBOOK TWITTER PINTEREST INSTAGRAM

Does fossilised dinosaur poo exist? →p79

CONTRIBUTORS

DR STUART CLARK
NASA is working on building an outpost in orbit around the Moon. Stuart reveals how the plans for the Lunar Gateway are shaping up. →p50

DR HELEN PILCHER
Helen delves into mRNA vaccines, the type used for some COVID-19 vaccines, which also may have the potential to prevent certain forms of cancer. →p44

CHRIS BARANIUK
Chris looks into the latest human right to be enshrined by the UN – the right to a clean environment – and what it might mean for people and the planet. →p60

DR PETER J BENTLEY
Why make machines that aim to replace us, when we could make machines that improve us? Peter lifts the lid the on the concept of augmented intelligence. →p72

CONTACT US

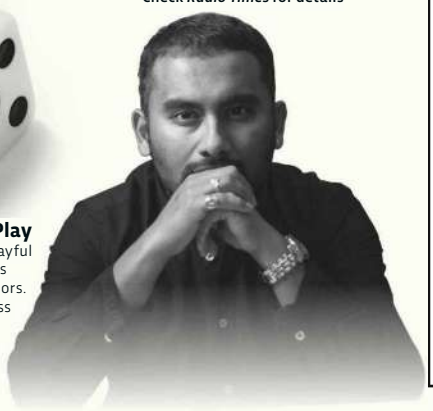
Advertising
David.DSouza@immediate.co.uk
0117 300 8110
Letters for publication
reply@sciencefocus.com
Editorial enquiries
editorialenquiries@sciencefocus.com
0117 300 8755
Subscriptions
buysubscriptions.com/contactus
03330 162 113*
Other contacts
sciencefocus.com/contact

ON THE BBC THIS MONTH...

The Green Planet
Sir David Attenborough travels the globe to gain a fresh understanding of the planet's plant life. He meets the largest living things that have ever existed and the plants that hunt animals.
BBC One
Check *Radio Times* for details

The Compass: Why We Play
Humans are the pre-eminent playful species – from babies' rattles through to bridge clubs for seniors. This series looks at play across cultures and through time.
BBC World Service
5 January, 8pm

Rethink: Population
Amol Rajan is joined by expert guests to examine long-held assumptions about the number of people in the world. Are there simply too many of us everywhere, or could it be that some places just don't have enough people?
BBC Radio 4
3 January
Check *Radio Times* for details



COVER: ANDY POTTS THIS PAGE: BBCX2, GETTY IMAGES, DANIEL BRIGHT

*UK calls will cost the same as other standard fixed line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Mon to Fri 9am-5pm. If calling from overseas, please call +44 1604 973721. *BBC Science Focus* (ISSN 0966-4270) (USPS 015-160) is published 14 times a year (monthly with a Summer issue in July and a New Year issue in December) by Immediate Media Company, Bristol, Eagle House, Bristol, BS1 4ST. Distributed in the US by NPS Media Group, 2 Enterprise Drive, Suite 420, Shelton, CT 06484. Periodicals postage paid at Shelton, CT and additional mailing offices. POSTMASTER: Send address changes to *BBC Science Focus*, PO Box 37495, Boone, IA 50037-0495.

CONTENTS

REGULARS

FEATURES

"THEY SENT ME SOME PHOTOS OF SALLY NEXT TO A MAMMOTH TUSK. I ASKED THEM, 'ARE YOU IN SIBERIA?' AND THEY SAID, 'NO, SWINDON'"

2021 IN IMAGES

FOR ANOTHER YEAR, COVID-19 HAS DOMINATED THE NEWS. BUT ALONGSIDE THE PANDEMIC, WE HAVE ALSO EXPERIENCED THE AWESOME IMPACT OF A CHANGING CLIMATE, WITNESSED TRAILBLAZING MISSIONS TO SPACE, AND SEEN SOME INCREDIBLE SCIENCE. HERE, IN PICTURES, ARE SOME OF THE STORIES THAT SHAPED 2021

On the rocks

ILULISSAT, GREENLAND
2 SEPTEMBER

This picture of Ilulissat's port in Greenland raises the question of why exactly there is ice floating in the water. The answer is becoming the response to an increasing number of enquiries: climate change.

Due to rising temperatures, 2021 saw Greenland experience the biggest melt of its ice sheet on record – enough to cover the entire state of Florida with five centimetres of water, according to Danish researchers. As parts of the ice sheet broke up, smaller chunks of ice ended up floating in Ilulissat's port. As if that wasn't concerning enough, for the first time in recorded history, rain fell onto the highest point of the Greenland ice sheet.

GETTY IMAGES

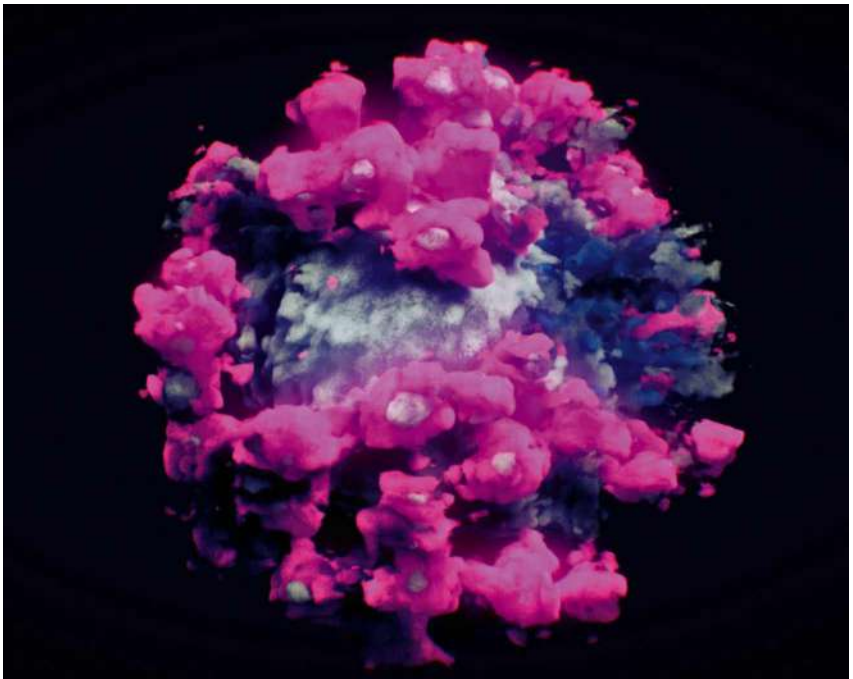
A shot in the arm

COVENTRY, UK
8 DECEMBER 2020

A round of applause from healthcare workers greets Margaret Keenan after she became the first person in Britain to receive the Pfizer-BioNTech COVID-19 vaccine. The 90-year-old grandmother was given her first dose on 8 December 2020 at University Hospital in Coventry to kick off the UK's mass vaccination programme.

When the time came for her second dose in April 2021, around 28 million people in England had been given at least one jab, and Keenan had turned 91. Keenan made the headlines again in September when she became the first person in the world (outside of a clinical trial) to receive a vaccine booster shot.

GETTY IMAGES, NANOGRAPHICS GMBH/NANOGRAPHICS.AT, NASA/JPL



So that's what you look like

BEIJING, CHINA
JANUARY

COVID continued to dominate the news, and everyone's lives, throughout 2021. But in January we got possibly our best look yet at the virus. By using a combination of cryo-electron tomography, machine learning and advanced visualisation algorithms, a team of experts from China's Tsinghua University, King Abdullah University of Science and Technology in Saudi Arabia, and Vienna-based Nanographics, produced this high-resolution 3D image of the SARS-CoV-2 virus.

We had images prior to this, but they were either models or composites constructed from different scans. This is the first single-scan, 3D image of the real virus (although the colours are artificial). You can see all 360° of it at **nanographics.at/projects/coronavirus-3d/**

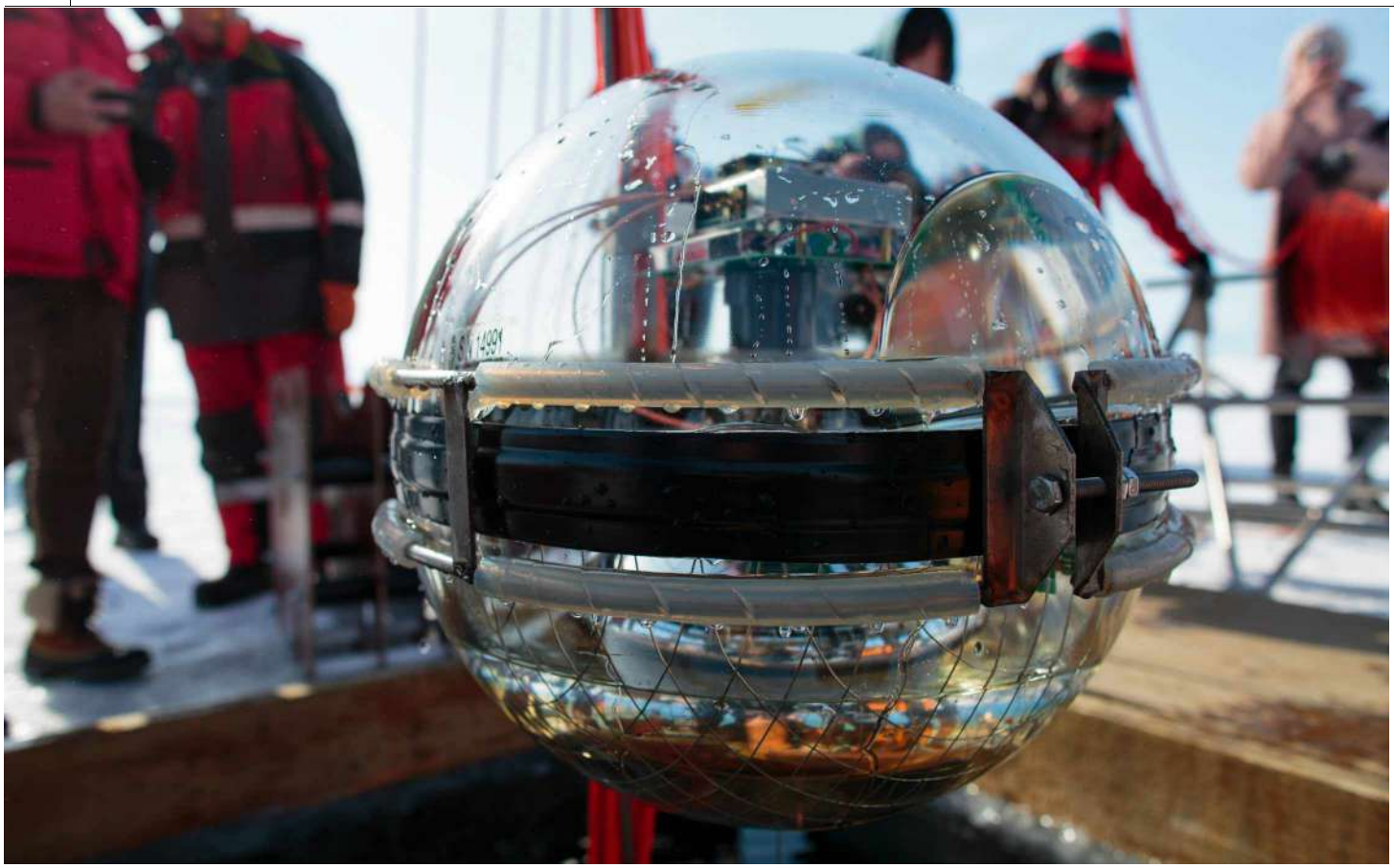
Wandering lonely, under a cloud

GALE CRATER, MARS
19 MARCH

Perseverance wasn't the only Martian rover making headlines in March. Curiosity got in on the act too, after snapping this shot of unusual clouds forming over Gale Crater, near the Red Planet's equator. It's unusual because the clouds formed earlier and higher than they usually do on this part of Mars.

The thin, dry atmosphere on Mars means clouds only tend to form when the planet's elliptical orbit takes it furthest from the Sun. These ones began appearing in January, sooner than they were expected, beginning as small, wispy puffs before becoming the more substantial bodies seen here in March.

Most clouds on Mars are formed by water crystals and float at altitudes of around 60 kilometres, but analysis by the Curiosity team on Earth suggests the clouds photographed in March are higher and are likely to contain frozen carbon dioxide.



Ghost detector

LAKE BAIKAL, SIBERIA
13 MARCH

It may not be what you typically think of as a crystal ball, but this strange-looking clear sphere could help us see ghosts. Ghost particles, that is, otherwise known as neutrinos. It's one of the optic modules being used in the Baikal-Gigaton Volume Detector – essentially a telescope made of eight vertical 'strings', each carrying 12 modules spaced 15 metres apart – being submerged around one kilometre below the ice of Siberia's Lake Baikal.

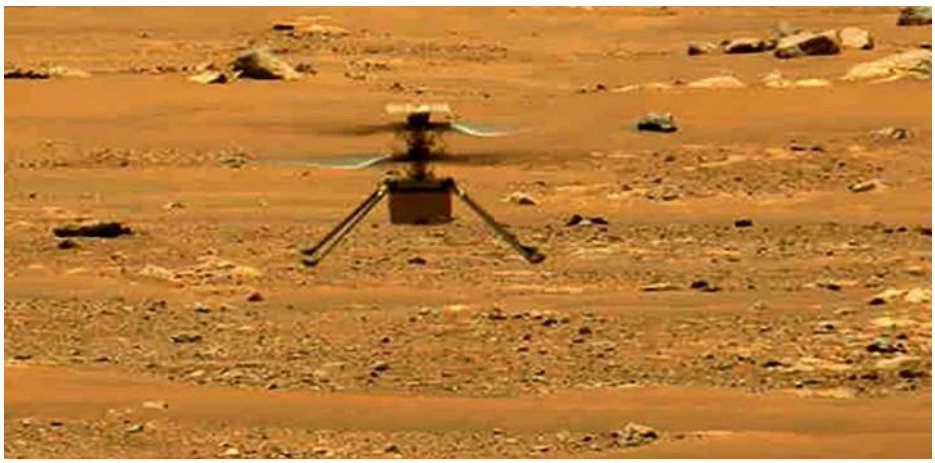
Neutrinos are thought to be the most abundant particle in the Universe, yet they have no electric charge, almost no mass and travel at nearly the speed of light. They're extremely difficult to study because they don't interact with matter or magnetic fields (hence they're ghost-like). But they do emit a type of light, known as Cherenkov radiation, when they hit water. And that's what the optic modules have been designed to pick up in the hope of confirming the existence of neutrinos and determining their sources.

We have lift off

JEZERO CRATER, MARS
22 APRIL

April saw the first powered, controlled flight of a human-made aircraft on another planet, when NASA's Ingenuity helicopter took to the Martian skies. The successful test flight, witnessed by cameras aboard the Perseverance rover, saw Ingenuity climb to an altitude of around three metres and hover for almost 40 seconds, before descending and – most importantly – landing safely.

The distance and signal delay between Mars and Earth meant Ingenuity's maiden flight couldn't be piloted by the team at Mission Control in NASA's Jet Propulsion Lab. Instead, it flew autonomously, relying on its own guidance, navigation and control systems. At the time of writing, Ingenuity had made 16 successful flights, reaching heights of five metres, making sideways transitions and capturing images mid-flight of the Jezero Crater below.



GETTY IMAGES, NICHOLAS PAPAS, ESA, NASA/JPL

Flying visit

VENUS
10 AUGUST

That big white swathe arching through this image is Venus, as seen by the BepiColombo spacecraft during its seven-year journey to Mercury. BepiColombo is actually a pair of spacecraft – the European Space Agency's Mercury Planetary Orbiter and the Japanese Aerospace Exploration Agency's Mercury Magnetospheric Orbiter – and it caught this image of Venus in August while using our planetary neighbour's gravity to slingshot itself on towards its final destination.

Once it reaches the smallest, innermost and least-explored planet in the Solar System, BepiColombo will study Mercury's surface, internal composition and magnetic field. Its aim is to shed more light on this mysterious planet along with planet formation in general.

Bigger and bolder

SYDNEY, AUSTRALIA
26 MAY

The Moon made a spectacle of itself in May by undergoing an eclipse while at perigee, a combination that resulted in this eye-catching Super Blood Moon.

Perigee is the name given to the point in the Moon's orbit that brings it closest to Earth, causing it to appear bigger than usual. The 'blood' part is, unsurprisingly, a result of it appearing red. This happens because as Earth passes between the Sun and Moon, the light that's still able to reach the Moon passes through Earth atmosphere, which scatters the light towards the blue end of the spectrum. Light at the red end is able to make it through, but not unscathed. The red wavelengths are stretched, so appear redder and give the Moon a distinctive hue when they are reflected off its surface.

The next total lunar eclipse will take place in May 2022, and will be visible from the Americas, Europe, Africa and parts of Asia.

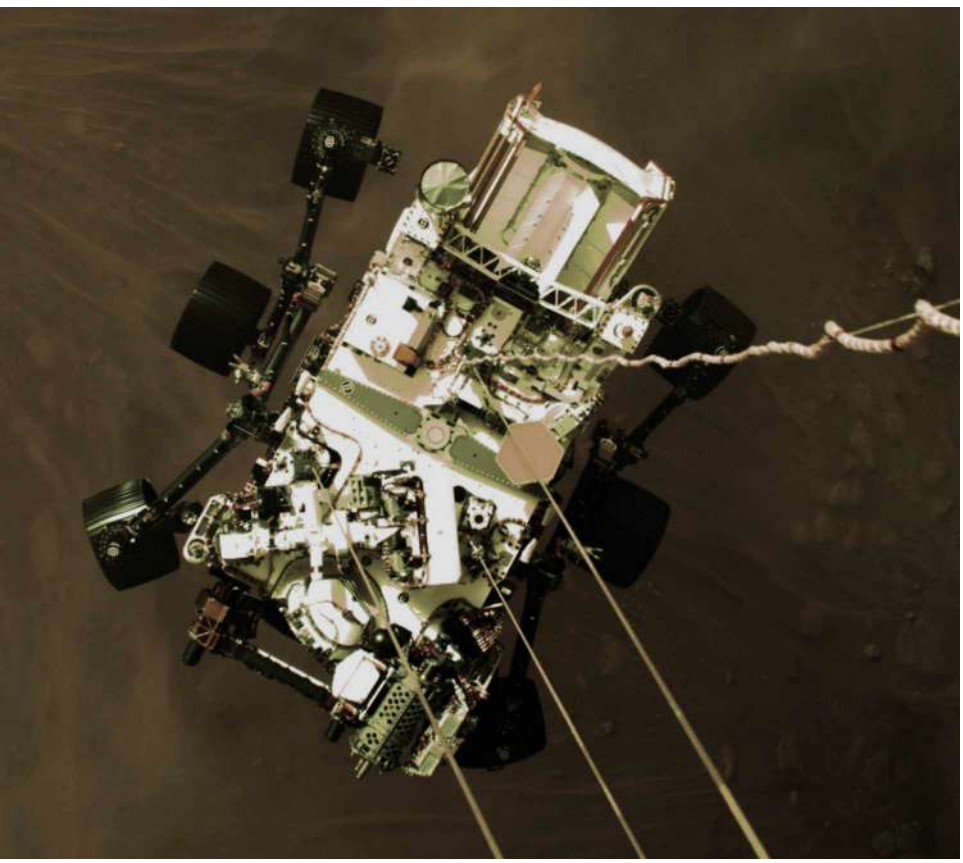
Time is money

SUEZ CANAL, EGYPT
27 MARCH

This might be the world's most expensive waiting room. The little white shapes spread around the lower left corner are container ships ffoating in Egypt's Gulf of Suez. They're queueing while engineers work to free another container ship – the 400m-long, 200,000-tonne *MV Ever Given* (near the top right corner) – after it ran aground in the Suez Canal on 23 March. This shot was taken on 27 March, two days before the ship was successfully reffoated.

Shipping analysts Lloyd's List estimated the blockage was holding up cargo worth $9.6bn (£7bn approx) each day. When it was finally freed on 29 March, the ship was immediately impounded by the Suez Canal Authority in a bid for compensation for the losses incurred during the salvage operation. The ship eventually set sail on 7 July.

GETTY IMAGES

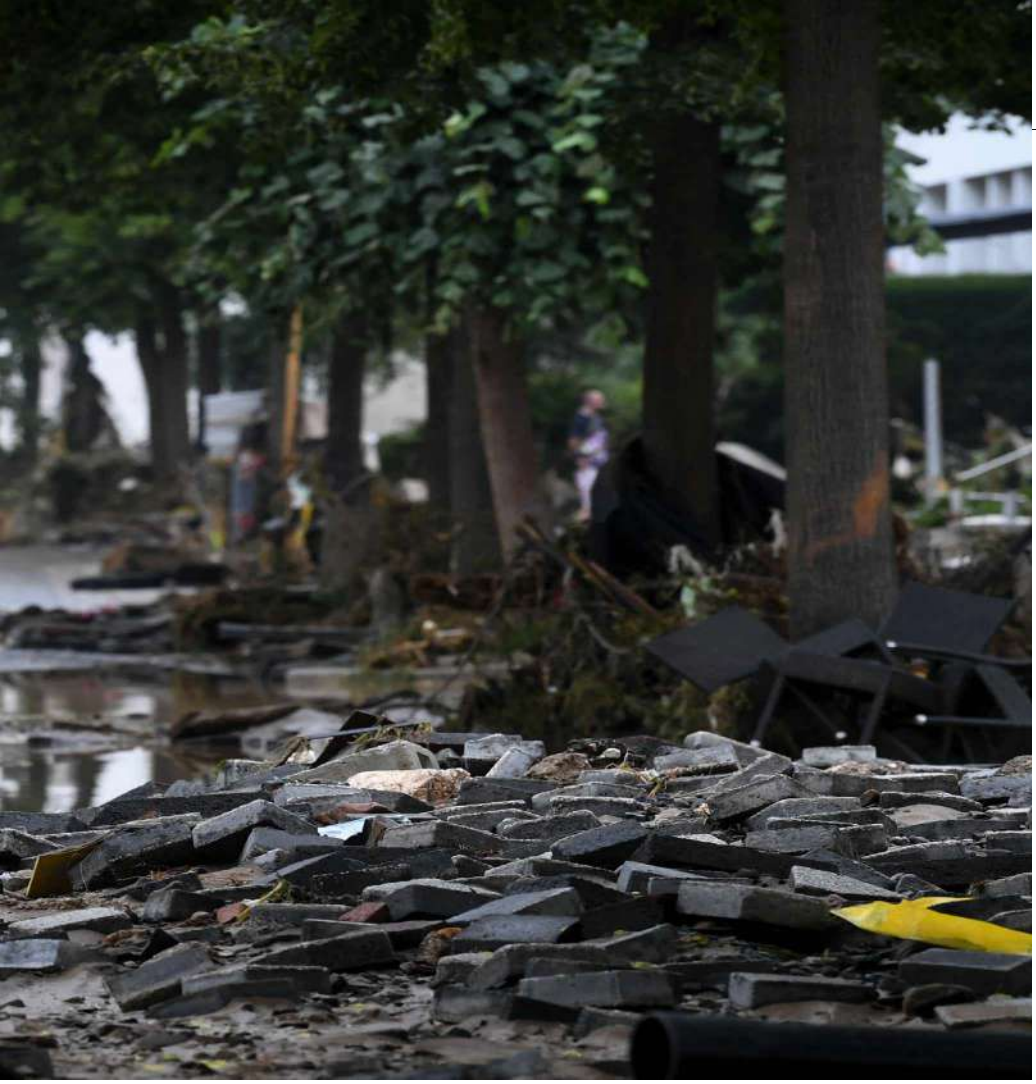


Touch down

MARS
18 FEBRUARY

This was the view from the Descent Stage as it lowered NASA's Perseverance Rover onto the surface of Mars. Essentially a jet pack, the Descent Stage used eight engines to bring the rover's plunge through the Martian atmosphere to a halt, before winching it down the last few metres to the ground.

This would be the last that the two vehicles saw of each other. After releasing the cables, the Descent Stage was programmed to fly off and make an 'uncontrolled' (crash) landing a safe distance from the rover. Perseverance, meanwhile, would begin exploring the surface and collecting samples that, in years to come, will be returned to Earth and analysed to learn about the planet's geology and climate to see if it could host life – whether it be microbes in the past or humans in the future.



Gone in a ash

BAD NEUENAHR-AHRWEILER, GERMANY
16 JULY

Record-breaking rainfall in Europe during July saw a number of countries devastated by flash floods and led to over 200 deaths across Germany (pictured here), Austria, Belgium, Italy and Romania. Cars, buildings and bridges were either damaged or entirely swept away, resulting in widespread power outages and, in some areas, emergency evacuations.

Officials in Austria's Tyrol province reported water levels reached heights that hadn't been seen in more than three decades. Studies carried out afterwards indicated that the rainfall over Belgium, the Netherlands and Germany had been 20 per cent heavier than usual due to climate change. It also found that further extreme weather events are now up to nine times more likely.

GETTY IMAGES, NASA/JPL X2

Handle with care

REDONDO BEACH, CALIFORNIA
OCTOBER

Packing for a long trip must be done thoughtfully and carefully, especially when your suitcase contains the $8.8bn (£6.5bn approx) James Webb Space Telescope (JWST) – seen here being prepared for its journey from Redondo Beach, California to the launch site in Kourou, French Guiana.

The suitcase for the JWST had to be specially made. It's a 5 x 4m construction that NASA calls STARRS (Space Telescope Transporter for Air, Road and Sea) and carried the JWST for the entire duration of its 16-day voyage, which included two trips on trucks equipped to carry oversize loads and a 9,800km (5,800-mile) cruise aboard the *MN Colibri* cargo ship. It arrived, in one piece, on 12 October.

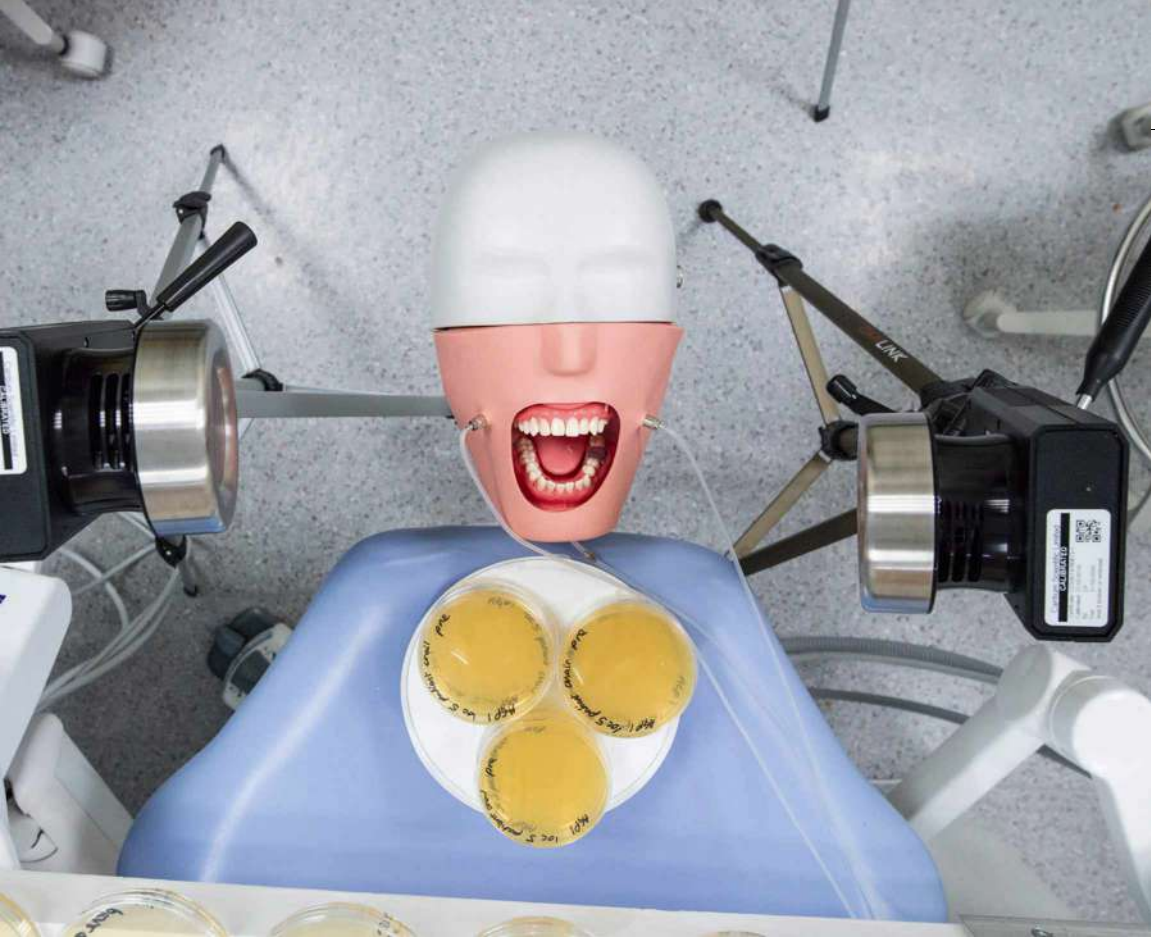
GETTY IMAGES

Miracle house

LA PALMA, CANARY ISLANDS
23 SEPTEMBER

Location is key when you're buying a house, especially if you're looking for property on an island known for its volcanic activity. This house on La Palma, the most northwesterly of Spain's Canary Islands, narrowly avoided the lava flows that devastated a vast tract of land after Cumbre Vieja erupted on 19 September.

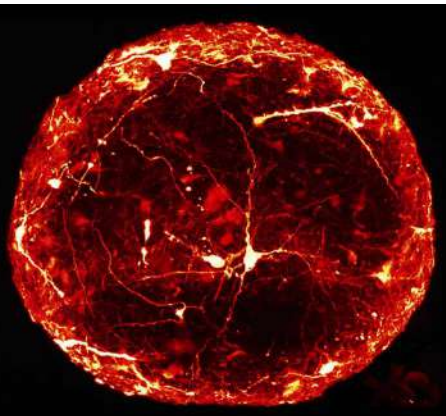
As pictures of the narrow escape began to circulate, it became known as the Miracle House. The miracle was short-lived, however, as the flows from the ongoing eruption had consumed the house by 30 September. Fortunately, its owners weren't occupying it at the time and despite the eruption continuing into November, perhaps miraculously, no deaths had been reported at the time of writing.



Say ahh...

LEEDS, UK
AUGUST

Thanks to this somewhat unsettling setup, your next trip to the dentist should be quicker and safer. It was part of a study, led by the University of Leeds, to determine which types of dental drills reduce the risk of spreading infections during dentistry procedures. The findings suggest that swapping high-speed air drills for slower electric drills could virtually eliminate the spray produced in the patient's mouth during a procedure. Less spray means less time needed to clean and prepare the surgery between appointments, which should help address the backlog that built up during the COVID-19 lockdowns.



Pea brain

GENEVA, SWITZERLAND
7 JANUARY

No, this is not some newly discovered planet plagued by raging lightning storms and ferocious tectonic activity. It's actually the first glimpse we've ever had of the internal structure of a mini-brain – a collection of brain cells no bigger than the size of a pinhead.

Mini-brains are grown from stem cells and could provide insights into how diseases and drugs affect the organ. Until 2021, the only way to see inside the mini-brains was to cut them into slices and examine them under a microscope; a slow, difficult procedure that can damage the samples. But scientists at the Geneva School of Engineering, Architecture and Landscape (HEPIA) and Wyss Center for Bio and Neuroengineering found a way to produce 3D images of intact mini-brains that could be used for analysis.

Bone head

PARIS, FRANCE
31 AUGUST

UNIVERSITY OF LEEDS, GETTY IMAGES, SPACEX, HEPIA

This gigantic skull belongs to Big John, the largest fossilised *Triceratops* ever found. In this image, which was taken in August, the fossil was in the process of being displayed in a gallery in Paris, ahead of going up for auction in October with the rest of its remains.

Unearthed in South Dakota in 2014, the three-horned herbivore would have been grazing on the landscape some 66 million years ago, during the Cretaceous. When Big John died, its body was submerged in mud, which preserved the skeleton. Palaeontologists were able to recover 200 pieces of the dinosaur (about 60 per cent), which went on to fetch a price of €6.6m (£5.6m approx) when sold at the auction.

Buckle up

KENNEDY SPACE CENTER, FLORIDA
15 SEPTEMBER

The four people pictured here are about to be blasted into Earth orbit. Nothing special about that, right? Not now everyone's so accustomed to spaceflight. The thing is, none of these individuals is an astronaut. Or at least, not until they reach space they're not.

They're tourists (from left: Chris Sembroski, Sian Proctor, Jared Isaacman and Hayley Arceneaux) and have hitched a ride aboard Elon Musk's SpaceX Crew Dragon capsule to become the first all-civilian crew to circle Earth from space, as part of the Inspiration4 mission. All four received commercial astronaut training from SpaceX. They spent three days in orbit after blasting off from Cape Canaveral, Florida, and returned safely, despite a technical issue with the capsule's waste management system. SF

CONVERSATION

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND *BBC SCIENCE FOCUS*

reply@sciencefocus.com
BBC Science Focus, Eagle House, Bristol, BS1 4ST
@sciencefocus
www.facebook.com/sciencefocus
@bbcsciencefocus

LETTER OF THE MONTH

More applicable advice, please

I wondered if you could please pass on to Dr Michael Mosley the news that some of us are wheelchair users. He yet again writes articles on health and fitness, totally ignoring our existence. I've also just listened to his podcast, informing me that due to me not standing, I'll die earlier from heart disease, diabetes and many other truly depressing things. Shall I just give up now?
Tony

Thanks for your letter, Tony; you make a very good point. My area of expertise does not include wheelchair users, who also tend not to feature much in the exercise research that I read. Time for that to change. I will try to do better in the future.
Dr Michael Mosley, *BBC Science Focus* columnist

WRITE IN AND WIN!
The writer of next issue's *Letter Of The Month* wins a **Logitech MX Keys Mini wireless keyboard.** The 30 x 13cm keyboard has been designed to help you work more comfortably. Its small dimensions let you keep your mouse closer to where your hands naturally fall, while its dished keys welcome your fingertips. It pairs to your computer via Bluetooth and will run for up to five months on a full charge. Find out more at **logitech.com**

The social aspect

I found 'Your Mysterious Brain' (November, p50) to be a real treat for my grey matter and enjoyed discovering what the various experts had to say as they delved into the mysteries of the most complex organ in our bodies. I particularly enjoyed Dr Christian Jarrett's contribution on how keep your brain healthy, happy and sharp, and will definitely be following his advice.

I found his mention of socialising to be rather apt, as many people are massively missing out, due to working from home and/or a reluctance to return to the office. People often assume that socialising is all about going out with your friends or family. But most socialising in an average week would be done in the workplace and people undervalue that at the peril of their mental health.

The fact also remains that we barely understand the brain, and many of its mysteries may never be solved – at least, not during our lifetimes. That should not stop scientists from trying though, as striving for knowledge, even if you fail to attain it, is its own reward.
Luke Russell

"Where'd everybody go?" Workplaces were where a lot of socialising occurred pre-COVID

"IT'S LIKE TRYING TO FIND NEEDLES IN A HAYSTACK, BUT THE NEEDLES ARE CHANGING SIZE, SHAPE AND COLOUR ALL THE TIME"

PROF MICHELE DOUGHERTY, P71

Ghosts: still so easy to dismiss when you're presented with the opportunity of possibly encountering one?

GETTY IMAGES X3, THOMAS ANGUS/IMPERIAL COLLEGE LONDON

Mixed drinks

This isn't a complaint, just pointing out a wee translation error. In Richard Graham's letter (November, p10), he says that we have a drink to take the place of tea: "uisge, or whisky". Richard is half right. Uisge is the Scottish Gaelic for water. Whisky is actually uisge beatha and means, as Richard correctly states, 'the water of life'.

We have a plentitude of both, to be sure, but uisge and uisge beatha are pretty different, and it wouldn't really be a good idea to get them mixed up... Although mixing them together is quite useful!

Iain Maclean

Real? No. Scary? Well...

I enjoyed Stephen Kelly's 'Popcorn Science: Do Ghosts Exist?' article (November, p90), in which he comes to the obvious conclusion that they do not. I agree with all his reasoning, but here's a point: I would bet any money that he wouldn't choose to spend a night, alone, in a so-called 'haunted house' to prove his point. To me this demonstrates that a kind of 'fear of fear itself' can still overcome cool, scientific detachment. A topic worthy of scientific investigation, perhaps?

Jim Gardiner

I'm glad you enjoyed the piece, Jim. I'd like to think that I would take you up on that bet, safe in the knowledge that "I ain't afraid of no ghost". But then again, I am reminded of the time, while staying over at a friend's house, that I came face-to-face with a mysterious figure in the dark. I froze in fear, unable to move – before gradually coming to the realisation that the figure wasn't moving either. It turned out to be my reflection in a distant mirror. So yes, maybe you're right.

Stephen Kelly, *BBC Science Focus* contributor

THE TEAM

EDITORIAL
Editor Daniel Benneff
Managing editor Alice Lipscombe-Southwell
Commissioning editor Jason Goodyer
Editorial assistant Amy Barreff
Online staff writer Sara Rigby
Staff writers Alex Hughes, Holly Spanner

ART
Art editor Joe Eden
Picture editor James Cutmore

CONTRIBUTORS
Scoff Balmer, Robert Banino, Chris Baraniuk, Peter J Bentley, Steve Boswell, Daniel Bright, Steve Brusaffe, Dean Burneff, Stuart Clark, Emma Davies, Alastair Gunn, Christina Kalli, Stephen Kelly, Aleks Krotoski, Pete Lawrence, Nish Manek, Michael Mosley, Jheni Osman, Helen Pilcher, Andy Poffs, Marcus du Sautoy, Colin Stuart, Luis Villazon, Joe Waldron.

ADVERTISING & MARKETING
Group advertising manager Gino De Antonis
Newstrade manager Rob Brock
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kellie Lane

MOBILE
Head of apps and digital edition marketing Mark Summerton

INSERTS
Laurence Robertson 00353 876 902208

LICENSING & SYNDICATION
Director of licensing and syndication Tim Hudson
International partners manager Anna Brown

PRODUCTION
Production director Sarah Powell
Production coordinator Georgia Tolley
Ad services manager Paul Thornton
Ad designer Julia Young

PUBLISHING
Publisher Andrew Davies
Group managing director Andy Marshall
CEO Tom Bureau

BBC STUDIOS, UK PUBLISHING
Chair, editorial review boards Nicholas Breff
Managing director, consumer products and licensing Stephen Davies
Director, magazines and consumer products Mandy Thwaites
Compliance manager Cameron McEwan
UK publishing coordinator Eva Abramik
Contact UK.Publishing@bbc.com
www.bbcstudios.com

EDITORIAL COMPLAINTS
editorialcomplaints@immediate.co.uk

ANNUAL SUBSCRIPTION RATES (INC P&P):
UK/BFPO £77; Europe & Eire £92.54;
Rest of World £102.90.

Audit Bureau of Circulations
45,132 (combined, Jan-Dec 2020)

IMMEDIATE MEDIA Co

ipso Regulated

BBC Science Focus Magazine is published by Immediate Media Company London Limited under licence from BBC Studios who help fund new BBC programmes.

PCSPECIALIST

CUSTOM GAMING

DESKTOPS & LAPTOPS

CUSTOM BUILT TO YOUR SPEC

EASY TO USE CONFIGURATOR

CUSTOM PCS & LAPTOPS

AWARD-WINNING SYSTEMS

COBALT ULTRA
GAMING DESKTOP

- Intel® Core™ i9-11900K
- ASUS® ROG Strix Z590-E Gaming WiFi
- 16GB Corsair VENGEANCE RGB Pro 3200MHz
- 8GB ASUS Strix GEFORCE RTX 3070 Ti
- 512GB PCS PCIe M.2 SSD
- 1TB SEAGATE BARRACUDA HDD
- Genuine Windows 11 Home

This spec from
£2,210.00*

ELIMINA
SERIES LAPTOP

- 15.6" Matte FHD Screen
- Intel® Core™ i7 11800H
- GeForce RTX 3050 / 3050Ti / 3060
- Multi-Colour Backlit Keyboard
- Genuine Windows 11 Home

This spec from
£940.00*

FUSION XT
GAMING DESKTOP

- AMD Ryzen 5 5600X
- ASUS® PRIME B550-PLUS
- 16GB Corsair VENGEANCE 3200MHz
- 12GB NVIDIA GEFORCE RTX 3060
- 512GB PCS PCIe M.2 SSD
- 2TB SEAGATE BARRACUDA HDD
- Genuine Windows 11 Home

This spec from
£1,290.00*

GET A FURTHER **£15 OFF**
WITH THIS EXCLUSIVE VOUCHER

BBF21

ORDER ONLINE NOW AT
WWW.PCSPECIALIST.CO.UK

0333 011 7000

*Prices are including VAT and are correct at time of printing, but subject to change.
Images are for illustration purposes only, components may differ in aesthetics and brand.

PCSpecialist

Photography and videography can change us.
They change the way we feel.
Our understanding.

They change our hearts and minds.
They change the rules.

Testing the limits of our comfort zones.
Changing the way others see the world.
See themselves.

Together let's change the way we do things.
Change the narrative.
Change the bigger picture.
Open up opportunity.
Give more people a voice.
Put camera kit in more hands.
Create a more sustainable future.
A future with more people included in it.
Here's to the stories to come.

MPB

ANCIENT BLING
Earliest evidence of human jewellery unearthed p28

HITCHING A RIDE
Coastal sea life found living on Pacific plastic patch p29

FAST CHARGER
Electric plane claims to have set new speed record p30

ROUTINE HEALTH
Disrupted body clock linked to inflammatory disease p31

DISCOVERIES

An artist's impression of the James Webb Space Telescope's initial deployment

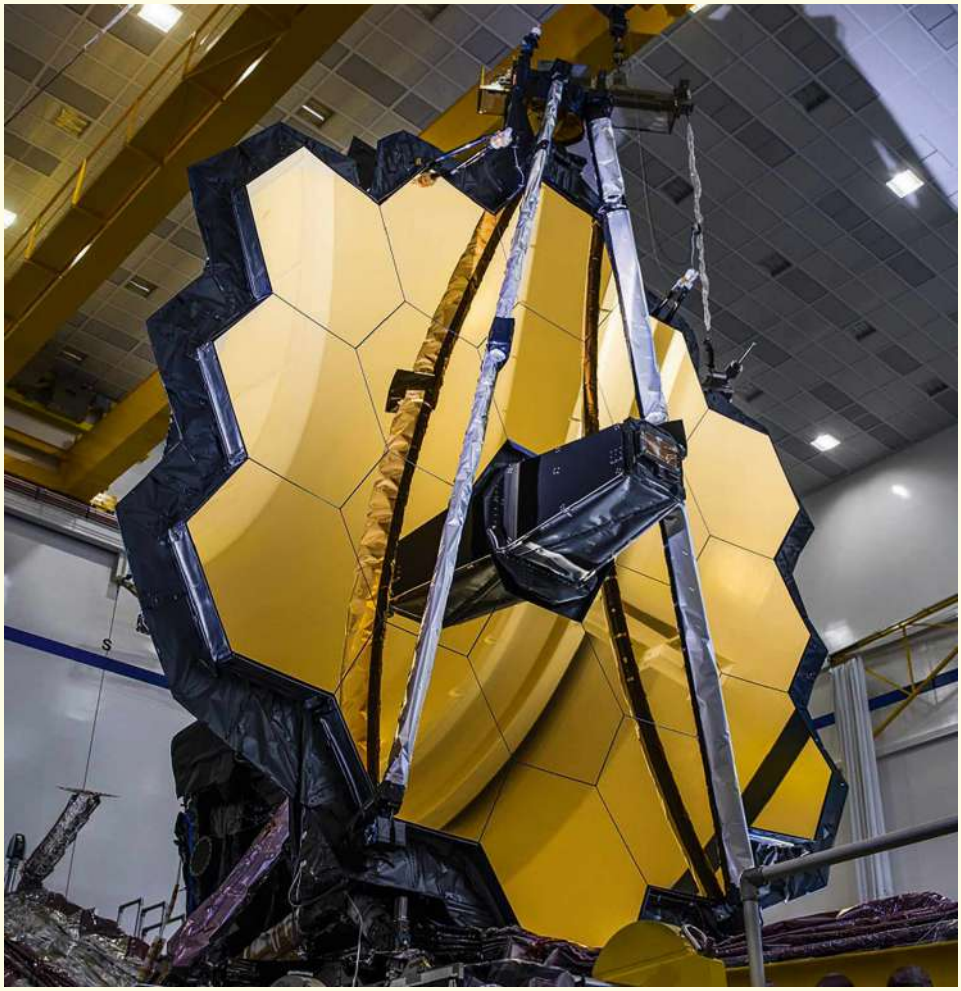
NASA/JPL

ASTRONOMY

IT'S TIME TO GET EXCITED ABOUT THE JAMES WEBB SPACE TELESCOPE

NASA's most ambitious project yet will peer deep into space looking for clues about the birth of planets, stars and the evolution of the Universe itself

Girls and boys Pollution may affect birth ratio p32 **Catch your breath** Post-exercise breathing difficulty hints at possible link between long COVID and chronic fatigue syndrome p33 **Swindon's mammoth** Huge fossil find explored in new Attenborough series p34



You might be tempted to think of the James Webb Space Telescope (JWST) as just another hyped-up space mission. Resist that temptation. The JWST is the most ambitious space telescope ever launched.

It's also the biggest gamble.

The JWST – or Webb, as NASA would like it to be known – is designed to reveal the evolution of the Universe, from its early phases to the modern era. It will do this by undertaking a thorough investigation of the Universe at infrared wavelengths.

To reveal the evolution of the Universe, Webb will target the origin of the various celestial objects that have emerged along the way. This begins in the distant, early Universe. Webb's cameras and instruments will focus on the first galaxies and the first stars to light up the Universe.

Today, the evidence suggests that there's probably a supermassive black hole at the centre of every galaxy. Yet how those black holes form is a mystery. Were they the gravitational seeds that catalysed galaxy formation, or did they form naturally at the centre of a gigantic gas cloud that was already coalescing to become a galaxy. Webb will investigate.

As for the first stars, no one knows what these were like, but theory suggests that they could be gigantic megastars, burning more brightly and hotter than anything in the Universe today. Webb will search for them.

It will also scrutinise the birth of stars and planets in the more recent Universe by peering inside the dusty nebulae that cocoon these nascent celestial objects.

Infrared light is uniquely suited to these investigations. In the case of the first stars and galaxies, they're so far away that the Universe has expanded greatly since their light began its journey. This expansion has caused that light to stretch, transforming what was once visible light into infrared light. And when it comes to looking inside the nebulae where stars and planets and born, infrared light is more penetrating than visible light. So observing at infrared wavelengths will allow astronomers to see deeper inside these dusty clouds.

Another reason for using infrared is that molecules are particularly interactive at those wavelengths. Therefore, studying the infrared light reflected or emitted by celestial objects allows the molecular composition of those objects to be studied. While the chemistry of a celestial object is interesting in its own right, these studies can also be used to gauge the habitability of planets. This is because chemistry is the essential stepping stone from physics to biology.

ON TARGET

Particular targets for Webb's molecular analysis include some of the thousands of exoplanets that have been discovered orbiting stars other than our own. Webb will also be a powerful tool for analysing the ices on the distant bodies in our Solar System, which may hold secrets relating to its formation.

Webb's science goals have been determined by the questions that the Hubble Space Telescope raised. This is why Webb is often said to be Hubble's successor, even though it operates at different wavelengths.

"We could be on the verge of a great watershed in our understanding of the Universe"

Hubble revolutionised our view of the Universe and changed our understanding of celestial objects. It is hoped that Webb will do the same. This new observatory will be stationed 1.5 million kilometres away in space. It'll take a month to reach its final orbit at the second Lagrange point (Lagrange

ABOVE LEFT The James Webb Space Telescope's primary mirror measures 6.5m in diameter when fully deployed

ABOVE Here, Webb is folded up for launch in a clean room at the launch site in French Guiana

NASA/CHRIS GUNN X2

points are particular locations in space where launched objects tend to stay put) and has been designed to last for at least 10 years.

But Webb's launch is a massive gamble, because it can't be launched in its final configuration. When operational, Webb is the size of a tennis court, with most of that being made up of the sunshield. This huge sunshield is necessary because in order to work at the infrared wavelengths that astronomers are targeting, the telescope must be protected from the Sun's heat. This sunshield is made up of five layers of high-tech material that must be rolled together and folded away during launch, then pulled out with a complex system of moving platforms and arms.

Then there's the telescope mirror itself. Webb's primary mirror is 6.5m in diameter (Hubble's was a 'mere' 2.4m) and it's too large to fit in the fairing of a rocket. So, like the sunshield, it has to be folded up for launch. How do you fold a mirror? Simple, you make it out of gold hexagonal segments and fit them with motors so that they be tucked out of the way.

It sounds impressive – indeed, it is impressive. But only if it works. The engineering challenge of building an unfolding telescope is unparalleled. This is one of the reasons that the telescope has taken a quarter of a century to develop and cost roughly $10bn to build.

That investment is what makes it all such a gamble. This telescope has absorbed so much time, effort and money that it's 'too big to fail'. In fact, it crossed that line years ago, which is how it unlocked more and more cash to overcome the substantial technological hurdles that it continued to encounter. And as more money was invested, so the pressure to get it right increased, which led to more tests, more delays, more money, more pressure and so on. Now comes the moment of truth.

On 22 December, Webb will be launched aboard a European Ariane 5 rocket. Once en route to its destination, ground operators will deploy each part of the telescope in a series of steps. It will take weeks, and at each step something could go wrong. That's not to say something will go wrong, but that potential is probably the biggest fear in the minds of everyone associated with the project.

When you watch it launch, wish Webb well, but remember that the launch is not the end of the story. As Han Solo said following a similarly dicey lift off from the planet Tatooine, "Here's where the fun begins."

So check in regularly in the days and weeks following the launch to find out how the deployment is going. By the end of January, Webb should be fully deployed and in its operating orbit. Then, in your best Han Solo voice, you can say, "Here's where the science begins."

The looping pattern is evidence of the skills and creativity of the people who made the Stajnia pendant

ARCHAEOLOGY

Earliest evidence of humans decorating jewellery unearthed in Polish cave

The 41,500-year-old ivory pendant is decorated with an ornate pattern of dots

From teenage social media stars to wizened old darts players, many of us are partial to a bit of bling. And according to a study carried out by researchers from Germany, Italy and Poland, it seems our ancient ancestors were too.

The researchers used radiocarbon dating to determine that an intricately decorated ivory pendant found in a cave among animal bones is 41,500 years old.

The object is the earliest known evidence of humans decorating jewellery to be found in Eurasia and could represent the emergence of the behaviour in human evolution, the researchers say.

The pendant was first unearthed in 2010 during an excavation that took place in Stajnia Cave in southern Poland – a site known to have previously been inhabited by groups of Neanderthals and *Homo sapiens*.

The team used cutting-edge 3D scanning and modelling techniques to virtually reconstruct the pendant and reveal its full form – including the decorative pattern punched into its surface made up of 50 marks that form an irregular looping curve, as well as two complete holes.

"This piece of jewellery shows the great creativity and extraordinary manual skills of members of the group of *Homo sapiens* that occupied the site. The thickness of the plate is about 3.7mm, showing an astonishing precision on carving the punctures and the two holes for wearing it," said co-author Dr Wioletta Nowaczewska of the University of Wrocław.

As yet, the team has been unable to determine what, if anything, the pattern represents. "[The question of whether] the Stajnia pendant's looping curve indicates a lunar analemma [a diagram of the Moon's movement] or kill scores remains open," Nowaczewska added.

The teams plans to carry out detailed analyses on other ivory objects found in Stajnia Cave. Studies of other sites in Poland are currently underway and promise to yield more insights into the strategies of production of personal ornaments in Central-Eastern Europe.

BIOLOGY

Animal and plant life has colonised the Great Pacific Garbage Patch

The finding marks the first time coastal life has been discovered living in the open ocean

The North Pacific Subtropical Gyre (or, as it's more commonly known, the Great Pacific Garbage Patch) is a 79,000-tonne mass of plastic waste, covering an area of 1.5 million km^2, floating between California and Hawai'i.

It's the largest of the world's five trash-filled gyres. They form when plastic and other forms of waste are swept out to sea by surface currents, before being trapped and gathered together into great masses by rotating currents.

Now, a study carried out by researchers at the Smithsonian Environmental Research Center (SERC), the University of Hawai'i and the Ocean Voyages Institute have found many coastal species – including anemones, hydroids and shrimp-like amphipods – making their homes on the North Pacific Subtropical Gyre's mass of plastic waste.

The researchers have dubbed these communities neopelagic, from 'neo', meaning new, and 'pelagic', meaning open ocean.

"The open ocean has not been habitable for coastal organisms until now," said SERC senior scientist Greg Ruiz, who heads the SERC's Marine Invasions Lab. "Partly because of habitat limitation – there wasn't plastic there in the past – and partly, we thought, because it was a food desert."

Using current models created by researchers at the University of Hawai'i to target the locations where plastic waste was most likely to pile up, the Ocean Voyages Institute team collected 103 tonnes of plastic and other waste from the North Pacific Subtropical Gyre. The SERC team then analysed this material.

> **"The issues of plastic go beyond just ingestion and entanglement"**

"The issues of plastic go beyond just ingestion and entanglement," said Linsey Haram, lead author of the study and former postdoctoral fellow at SERC. "It's creating opportunities for coastal species' biogeography to greatly expand beyond what we previously thought was possible."

The team is still unsure how the neopelagic colonies are finding food. It's possible they're drifting into existing food hotspots or perhaps the plastic itself is acting as a reef and attracting food sources to it, they suggest.

Neither is the team sure how common the colonies are, or if they even exist outside the North Pacific Subtropical Gyre. As the production of global plastic waste continues to increase, however, the team thinks it likely that these colonies of coastal rafters will continue to grow.

ANTONINO VAZZANA/BONES LAB, SMITHSONIAN INSTITUTION, OCEAN VOYAGES INSTITUTE 2020 GYRE EXPEDITION

A member of the Ocean Voyages Institute team retrieves plastic collected from the North Pacific Subtropical Gyre in 2020 (left). Various coastal species have colonised the plastic debris (above)

Rolls Royce's all-electric *Spirit Of Innovation*

AVIATION

Rolls-Royce claims its all-electric plane is the fastest ever made

The new electric aircraft, *Spirit Of Innovation*, clocked a top speed of 623km/h (387.4mph). Could it help us reach 'jet zero'?

Two months after first taking to the skies, *Spirit Of Innovation*, Rolls-Royce's all-electric plane, has hit what its makers claim to be a record-breaking top speed of 623km/h (387.4mph).

The aircraft, which is part of the Rolls-Royce-led Accelerating the Electrification of Flight (ACCEL) project, smashed the previously held record for an electric plane by 213.04km/h (132mph).

Rolls-Royce has submitted the data to the Fédération Aéronautique Internationale (FAI) – the World Air Sports Federation that controls and certifies world aeronautical and astronautical records – to confirm that it has broken the world record.

Spirit Of Innovation achieved this feat thanks to a 400kW electric powertrain and a 6,480-cell, 750V battery. To put that into perspective, the battery has enough energy to juice up 7,500 smartphones. These drive a propeller that spins at over 2,200 revolutions per minute.

The aim of ACCEL is to research battery technology for future electric aeroplanes, including commercial aircraft.

"*Spirit Of Innovation* is a bit different from other existing electric-powered aircraft in that it has been optimised for speed, which means that the batteries are used up very quickly – the aircraft can only fly for around seven to eight minutes with enough power remaining to land with reserves," said Bill Read, deputy editor of *Aerospace*, the magazine of The Royal Aeronautical Society.

"Future designs for electric commercial aircraft will be concentrating more on endurance to keep the batteries running for as long as possible to increase range."

With rising concerns about the effect of aviation emissions on the environment, there has been an increasing focus on the development of electric planes.

"The advanced battery and propulsion technology developed for this programme has exciting applications for the advanced air mobility market," said Rolls-Royce CEO Warren East.

"Following the world's focus on the need for action at COP26, this is another milestone that will help make 'jet zero' a reality and supports our ambitions to deliver the technology breakthroughs society needs to decarbonise transport across air, land and sea."

Scientists have been experimenting with electric flight since the end of the 19th Century, when French aviator Gaston Tissandier flew an electric airship. But electric flight is currently impractical for your annual holiday to the Mediterranean, as any plane that had sufficient battery power for long flights would be too heavy to take to the skies.

Instead, many manufacturers are working on planes that could be used for short-haul flights or as air taxis. For example, EasyJet is developing a fully electric 186-seater plane that could fly for about an hour, which would be sufficient to take you from London to Amsterdam. Meanwhile, Urban Air Port plans to build a skyport in Coventry, which will be the world's first operational hub for air taxis and cargo drones.

According to Read, Rolls-Royce wants to use the experience gained from the ACCEL project in the development of a complete electric propulsion system for electric vertical take-off and landing (eVTOL) air taxis and larger electric-powered commuter aircraft.

ROLLS ROYCE, SCIENCE PHOTO LIBRARY

HEALTH

There is a link between inflammatory diseases and a disrupted body clock, new research finds

Working the night shift or not getting enough sleep can have a serious impact on your health

The circadian rhythm, or body clock, controls a huge variety of bodily processes. Our 24-hour sleep-wake cycle has an effect on everything, from alertness throughout the day to our digestive system and even how susceptible our skin is to sunburn. A new study has revealed that it could even play a role in inflammatory diseases by affecting how much fuel our immune cells use.

Inflammation is a normal and healthy part of our immune systems. When your body is injured or catches an infection, blood flow to the affected area is increased, which provides more white blood cells and proteins, and washes away debris.

Sometimes this system goes wrong, however, and creates inflammation where there is no infection or injury; this is known as an inflammatory disease. This can cause pain and loss of function, such as the swollen joints common in arthritis patients. Other inflammatory diseases include heart disease, obesity and diabetes.

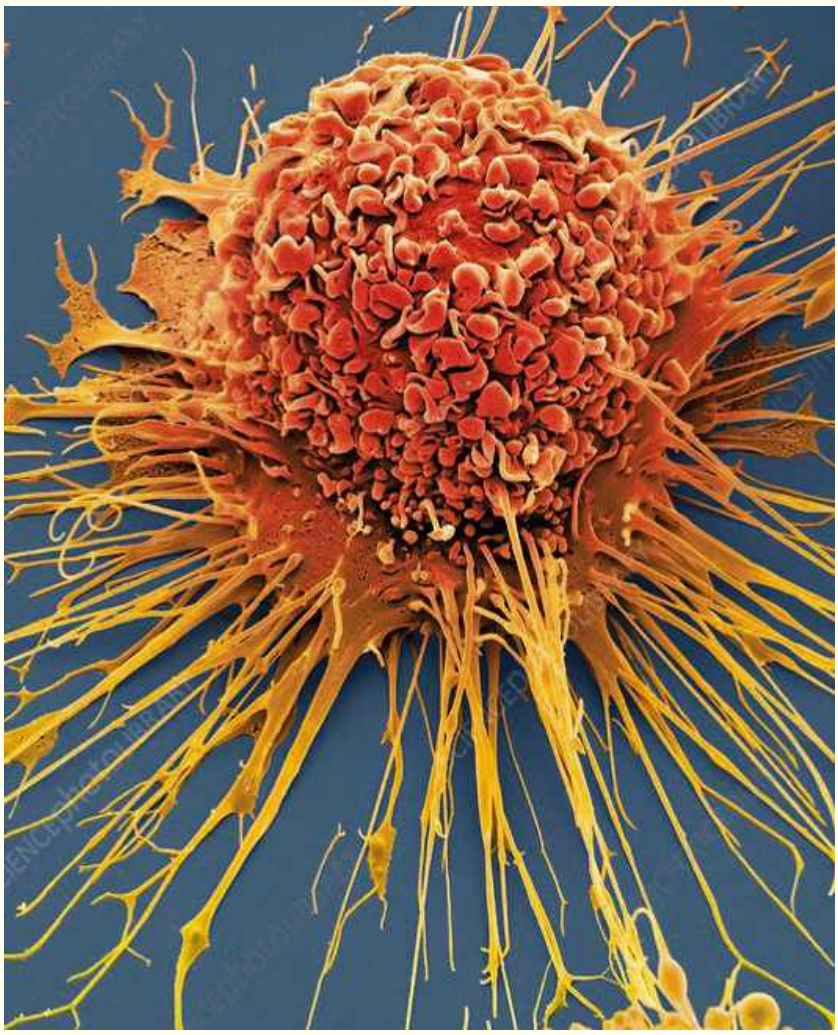
The study, led by researchers at the Royal College of Surgeons in Ireland, looked into circadian rhythms in a type of white blood cell called macrophages. The 24-hour cycle of these cells is controlled by a protein called BMAL1, so the researchers studied two groups of mice: those that had the gene that encodes BMAL1, and those without it. The mice without the protein represented the disrupted body clock.

The researchers found that when macrophages were deficient in BMAL1, they used more glucose and their mitochondria (cell power stations) broke this glucose down by a different set of processes. This resulted in the mitochondria producing reactive oxygen species – chemicals that are necessary in small amounts, but in larger amounts can cause inflammation.

"Our results add to the growing body of work showing why disruption of our body clock leads to inflammatory and infectious disease," said Dr George Timmons, lead author of the study. "And one of the aspects is fuel usage at the level of key immune cells such as macrophages."

"This study also shows that anything which negatively impacts on our body clocks, such as insufficient sleep and not enough daylight, can impact on the ability of our immune system to work effectively," said Dr Annie Curtis, senior author on the paper.

BELOW An activated human macrophage, seen under a coloured scanning electron micrograph



Neither food cravings nor the number of magpies you've seen are reliable indicators of the sex of your baby

REPRODUCTION

Air and water pollutants linked to changes in sex ratio of babies

Temperature seems to be off the hook, but Iron, lead, mercury and carbon monoxide may play a role in determining the sex of unborn human children

The presence of pollutants in the air and water is associated with changes in the ratio of boys and girls born, a study led by Dr Andrey Rzhetsky of the University of Chicago, has found. It's not clear whether these pollutants caused the change, however.

Environmental factors can affect the likelihood of offspring being male or female in some non-human species. For example, in many reptiles and fish, the incubation temperature determines the sex of the eggs.

Humans do have many folk tales about what affects the sex of a baby, from what the expectant parents eat, to how the baby is conceived. But although there have been some small studies, little is known for certain about what environmental factors can play a role in determining a baby's sex.

The ratio of boys to girls, as assigned in the hospital at birth, is known as the sex ratio at birth (SRB). A higher SRB means more boys, while a lower SRB means more girls. Generally speaking, the SRB is tilted slightly in favour of boys, though it changes with geography and time.

Previous studies have used small datasets to investigate whether pollutants, changes in weather or psychological stress could affect the SRB. In this study, a team of scientists led by Rzhetsky compared records of six million births with environmental data from national databases. They looked at three million births in the USA between 2003 and 2011, and a further three million in Sweden from 1983 to 2013.

They found no link between the SRB and ambient temperature, seasons, unemployment rate or violent crime rate. Some pollutants did affect the ratio, however. Iron and lead in soil brought the SRB down (so more girls were born), whereas polychlorinated biphenyls (PCBs), mercury, carbon monoxide, aluminium in air, and chromium and arsenic in water all increased the SRB (meaning more boys born).

While the researchers can't say for sure whether the pollutants are changing the ratio, they do say that they hope the results will encourage policymakers to tackle environmental pollution.

HEALTH

Chronic fatigue syndrome and long COVID may overlap

Small study finds abnormal breathing patterns in people experiencing long COVID that may be shared by those suffering from chronic fatigue

Around 1.2 million people in the UK are living with long COVID – a condition that sees them continue to experience COVID-19 symptoms for prolonged periods. The symptoms may persist for weeks, months and, in some cases, more than a year after the initial infection.

The most common long COVID symptom reported is fatigue, which has led some to question whether the condition could be the same as chronic fatigue syndrome (CFS).

Also referred to as myalgic encephalomyelitis (ME), CFS is a long-term condition that causes people to experience extreme fatigue, particularly after exercise, in addition to problems with sleeping, physical pain, and confusion known as brain fog. Scientists have yet to determine the cause of ME/CFS, but the onset of the condition in many patients follows infection with a virus or bacteria.

Experts are unable able to confidently say whether CFS is a part of long COVID. But a new study, by researchers at Icahn School of Medicine at Mount Sinai in New York, has tested 41 long COVID patients against CFS diagnostic criteria.

Of the group studied, 46 per cent of participants had four or more symptoms of ME/CFS and had experienced a substantial impact to their lives as a result of fatigue. A further 13 individuals with long COVID were put through the study's exercise tests, but were not recorded as meeting the ME criteria on account of having either a high body mass index or a cardiac disease.

The researchers ran cardiopulmonary exercise tests on each of the long COVID sufferers to assess how their breathing was affected by physical activity. The participants were told to pedal on a stationary bicycle until they reached the point of exhaustion. But while they were pedalling, the difficulty of the effort required to keep the pedals turning was increased by 25 Watts every three minutes.

Most of the participants (36 out of 41) showed abnormal respiration – rapid, shallow breathing similar to that of people with asthma – and a majority had chronic hyperventilation after the exercise test.

"Many of these patients reported shortness of breath and the cardiopulmonary exercise test is often used to determine its underlying cause," said Dr Donna Mancini, professor in the department of cardiology at Mount Sinai and lead author of the study.

"These findings suggest that in a subgroup of [long COVID patients], hyperventilation and/or dysfunctional breathing may underlie their symptoms. This is important, as these abnormalities may be addressed with breathing exercises or 'retraining'," said Mancini.

Mancini said there could be several subsets of patients suffering from long COVID, including those who have ME/CFS-like symptoms.

"The most common long COVID symptom reported is fatigue"

Coronavirus symptoms appear to vary in both severity and longevity

GETTY IM AGES X2

PROF BEN GARROD
Evolutionary biologist

Horizons

An archaeological site, found by accident, contains a whole herd of mammoth fossils

Ben Garrod, presenter and researcher of new BBC show *Attenborough And The Mammoth Graveyard*, tells us about this fascinating find, which could be one of the most important mammoth discoveries ever made

DIDN'T THE WHOLE STORY START WITH A CHANCE DISCOVERY BY AMATEURS?

Back in 2017 Sally and Neville Hollingworth, who are amateur fossil hunters, came to a talk that I did. Not long afterwards they got in touch asking if they could send me some photos of a discovery they'd made. Long story short, they sent me some photos of Sally lying next to a mammoth tusk.

So I asked them, "Are you in Siberia?"And they said, "No, Swindon." That wasn't the answer I expected. I said quickly that I shouldn't really know about this because, obviously, whoever's in charge academically would have a fit. But they told me that no one knew it was there; it was just in a quarry, and they asked me if I wanted to be involved. I took the reins and helped put a team together with Lisa Westcott Wilkins from DigVentures and bunch of academics from institutes around the UK.

HOW DID SIR DAVID ATTENBOROUGH BECOME INVOLVED?

I showed him a series of photos when we were at a conference together and it wasn't hard to hook him on such an amazing project. For me, to work with David on such a big project was always going to be amazing, but what is most lovely about this project is that it showcases the science. We don't do that enough in media, unfortunately. It's often just the end product that's shown. This shows the process going on behind the scenes, like those 10-minute 'How we filmed…' shorts at the end of the big, glossy shows David usually does. This is really seeing who's involved, what they're doing, how the discoveries have been made.

SWINDON DOESN'T IMMEDIATELY STRIKE ME AS A MAMMOTH HOTSPOT…

If you go back a quarter of a million years, you would have had this diagonal cut across the country, from north Norfolk through Swindon and Oxford, right down to the south coast. North of that would've been this huge icy tundra that wasn't especially hospitable. South of that would've been this lush, quite productive zone where you had animals and people migrating backwards and forwards, up and down. You're talking about a whole range of different animals here: bear, bison, turtles. It would have been a hugely important migratory route a quarter of a million years ago.

SO, THIS IS A MAMMOTH GRAVEYARD. WHEN WE'RE TALKING ABOUT MAMMOTHS WHAT EXACTLY ARE WE TALKING ABOUT?

The mammoth group is a really interesting group. From fossil records we know that the group spans from about five million years ago, when they first evolved in Africa and then, like our species, spread out and ended up in North America, and across Europe and Asia. Then they diversified. There are about 10 known species from the woolly mammoth right through to steppe mammoths.

The mammoth group as a whole died out maybe as recently as 3,600 years ago. So we still had mammoths roaming the planet when Stonehenge was built. We think of these things as living hundreds of thousands of years ago, but they were around just a few generations ago.

WHICH SPECIES DO THE SWINDON MAMMOTHS BELONG TO?

The species that we have in Swindon are steppe mammoths, so steppe as in the Siberian steppes. These things were absolute monsters – the largest mammoths that ever existed. They reached up to about 15 tonnes, maybe even more, and had tusks over four and a half metres long. But the ones we've got were right at the end of their range – this particular species came onto the scene about 1.8 million years ago and disappeared about 200,000

Sir David Attenborough with a selection of mammoth bones unearthed from the site in Swindon

BBC PICTURES X2

"Just finding one mammoth is amazing, but we've got a herd with babies in it"

years ago. Ours lived about 200,000 years ago. At that time, this very large species was becoming much smaller, thanks to selection pressure from environmental change, climate change, competition with other big herbivores, and predation from our species and other animals. These [later mammoths] are much more comparable to African/Asian elephants, but we're still talking 8, 9, 10 tonnes potentially.

WHAT WORK HAS BEEN HAPPENING AT THE SITE SINCE 2017?

The really important thing about this site is that it's not just a bunch of mammoth bones – that would be cool in itself but, if you have that, there's no context. If I say to you, this is a piece of mammoth tusk, maybe you can do radioisotope analysis, but you can't tell me what the environment was really like for the animal it came from.

We've got mammoth bones, mammoth tusks, hand-axes from Neanderthals, we've got other species such as bears and *Megalosaurus*, even the mud – I've been singing the praises of the mud for so long now. What we have is so well-preserved, we know exactly what the water flowed like, we know what the salinity was like, we know what the oxygen content of the environment was like, we've even got freshwater snail shells so we know exactly – from the biggest to the smallest – what animals lived within that environment.

If you've heard of the *Mary Rose*, the ship that sank off the south coast in the 1500s, that served as a snapshot of what life was like in Tudor Britain because so much of it was there; it wasn't just a cannon, or a cutlass, it was everything. It's the same thing here but from a quarter of a million years ago.

WHAT NEW APPROACHES HAVE YOU BEEN TAKING?

We've been looking at this site from a different perspective to what you would normally see in a palaeontology project. We've made sure that we had a team of archaeologists led by Lisa and Brendon Wescott Wilkins. They run DigVentures, a commercial archaeology unit that's based on citizen science and is outward-facing and very collaborative. They use Light Detection and Ranging (LIDAR) scans and drones, as well as more classic techniques. We've also tried to look at environmental DNA – so taking water and mud samples to see what other animals urinated, defecated, bled to death or decomposed in the area. You might not find the animals themselves, but you might find that a Neanderthal had a wee nearby. We've also been using ground-penetrating radar to look at the environment.

The frustrating but cool thing is that we've barely scratched the surface. In my mind we've only got maybe 10 per cent of the files that are going to come out of this site. The rest of it is still there, still waiting to be found, still waiting to be explored and researched properly.

WHAT ARE YOUR FINDINGS SO FAR?

This is one of, if not the only example of what could turn out to be a herd of steppe mammoths found anywhere in the world. Just finding one mammoth is amazing, but we've got a herd with babies in it, which is incredible. It doesn't get any better than that. We also definitely have an association with Neanderthals here. This is one of the earliest examples, anywhere in the world, of Neanderthals interacting with mammoth remains. I can't definitively say yet what the link was between them. We don't know whether they found them dead, and then butchered them, or whether they killed them and then butchered them. But that [research] is all ongoing. SF

PROF BEN GARROD
Ben is a broadcaster, author and professor of evolutionary biology and science engagement at the University of East Anglia, Norwich.

SFP372

BBC Science Focus MAGAZINE SUBSCRIPTION ORDER FORM

Please complete the order form and send to:
FREEPOST IMMEDIATE MEDIA *(please write in capitals)*

UK DIRECT DEBIT

☐ Yes, I would like to subscribe to/renew *BBC Science Focus* paying £22 every 6 issues – 2 issues free*

YOUR DETAILS (ESSENTIAL)**

Title _____ Forename _____
Surname _____
Address _____
_____
_____ Postcode _____
Home phone no _____
Mobile phone no** _____
Email** _____

☐ **I wish to purchase a gift subscription**

GIFT RECIPIENT'S DETAILS (ESSENTIAL)**

Title _____ Forename _____ Surname _____
Address _____
Postcode _____ Home phone no _____
Mobile phone no** _____
Email** _____

Instructions to your bank or building society to pay by Direct Debit DIRECT Debit

To: the Manager (bank/building society)

Address

Postcode

Name(s) of account holder(s)

Bank/building society account number

Branch sort code

Reference number (internal use only)

Originator's identification number

7 1 0 6 4 4

Please pay Immediate Media Co Bristol Ltd debits from the account detailed in this instruction subject to the safeguards assured by the Direct Debit Guarantee. I understand that this instruction may remain with Immediate Media Co Bristol Ltd and, if so, details will be passed electronically to my bank/building society.

Signature

Date / /

Banks and building societies may not accept Direct Debit mandates from some types of account

KEEP IN TOUCH

BBC Science Focus Magazine* (published by Immediate Media Company Limited) would like to send you updates, special offers and promotions by email. You can unsubscribe at any time. **Please tick here if you would like to receive these ☐

We would also like to keep in touch by post and telephone about other relevant offers and promotions from Immediate Media. For more information about how to change the way we contact you, and how we hold your personal information, please see our privacy policy, which can be viewed online at **immediate.co.uk/privacy-policy**

OTHER PAYMENT METHODS

☐ **UK cheque/credit/debit card** – £57.75 for 14 issues, **saving 25%**
☐ **Europe** inc Eire – £92.54 for 14 issues
☐ **Rest of world** – £102.90 for 14 issues
☐ I enclose a cheque made payable to Immediate Media Co Ltd for £ _____

Visa ☐ Mastercard ☐ Maestro ☐

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Issue no ☐☐ Valid from ☐☐☐☐ Expiry date ☐☐☐☐

Signature _____ Date _____

If credit card address is different, please use the order hotline 03330 162 113

OVERSEAS Please complete the order form and send to: *BBC Science Focus Magazine*, PO Box 3320, 3 Queensbridge, Northampton, NN4 7BF

***Offer ends 20 January 2022.** Two free issues deal is only available to UK residents paying by Direct Debit. Personal subscriptions will start with the next available issue.

You may photocopy this form

EASY WAYS TO ORDER

ONLINE

buysubscriptions.com/SFP372

PHONE

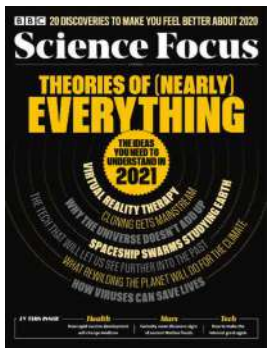
03330 162 113†
(please quote SFP372)

POST

FREEPOST IMMEDIATE MEDIA
(please write in capitals)

† UK calls will cost the same as other standard fixed line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages, call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Mon to Fri 9am-5pm. *If calling from overseas, please call +44 1604 973 721.*

FSC www.fsc.org MIX Paper from responsible sources FSC® C020508



JANUARY SALE INTRODUCTORY OFFER!

TWO FREE ISSUES

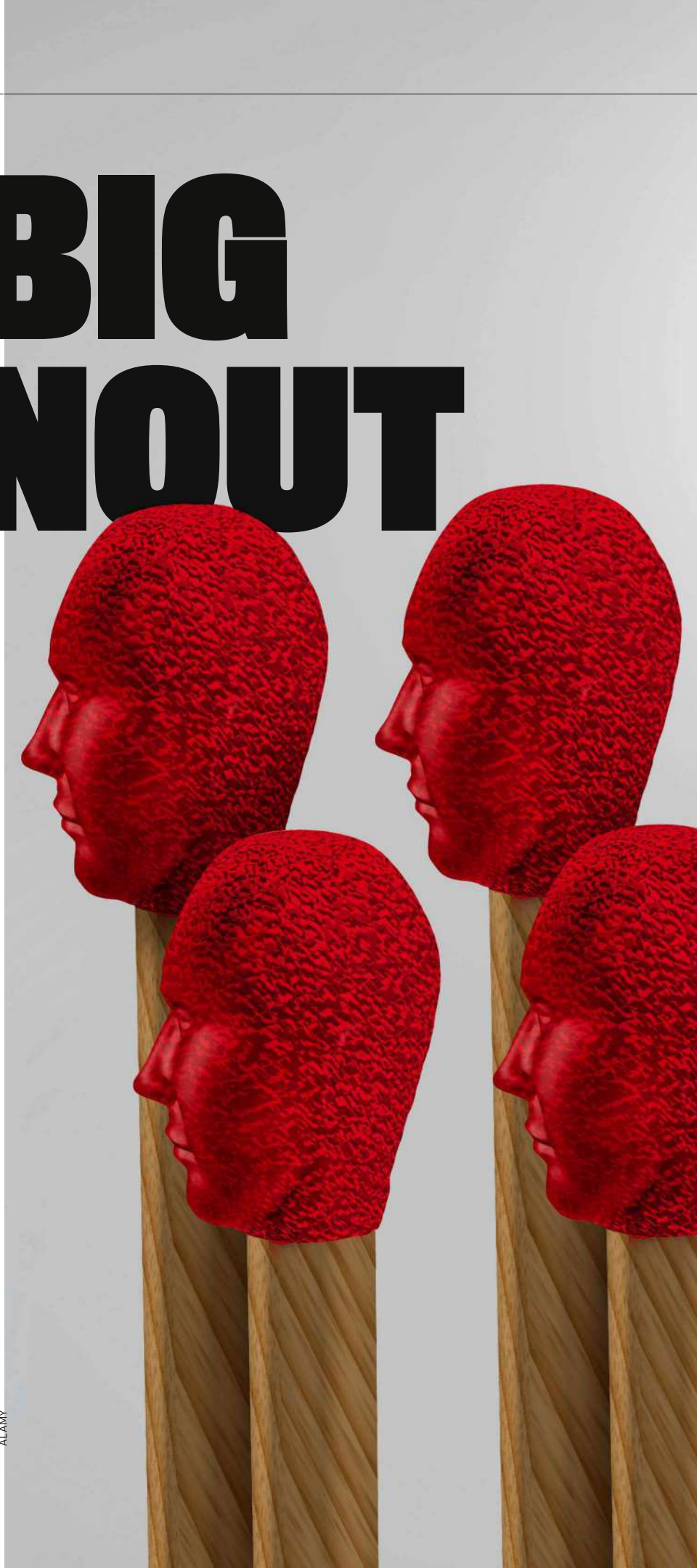
WHEN YOU SUBSCRIBE TO *BBC SCIENCE FOCUS* TODAY*

- Get 2 free issues – 6 issues for the price of 4!
- Spread the cost and pay just £22 every 6 issues by Direct Debit, that's 2 issues free!*
- Receive every issue delivered direct to your door with FREE UK delivery

THE BIG BURNOUT

Long hours, low pay and a lack of appreciation – among other things – can make for a stressful workplace and lead to burnout. It's something we should all be concerned about, because over half of the workforce reports feeling it

by DR DEAN BURNETT

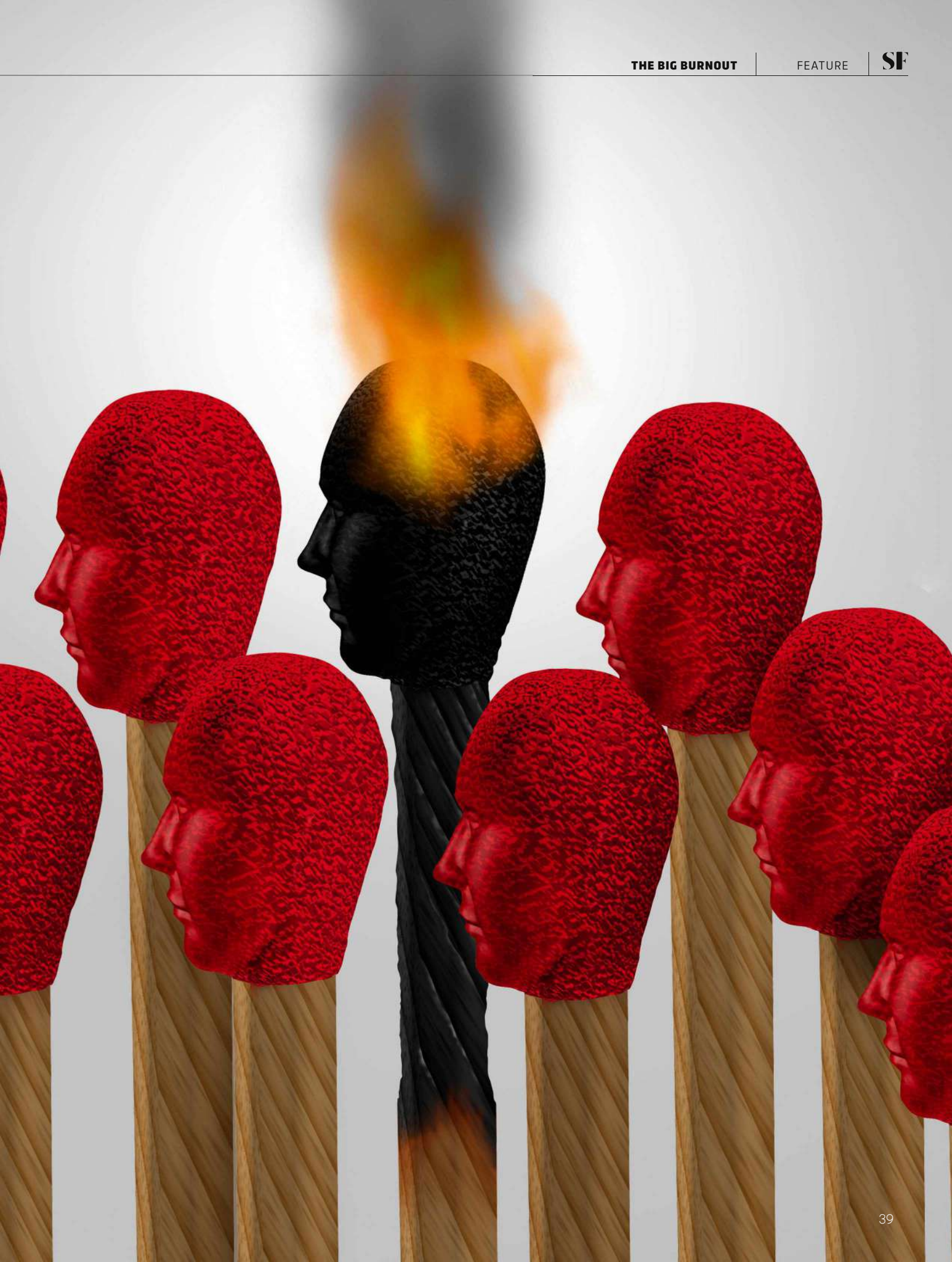


ALAMY

Burnout is mentioned a lot these days. But what is it, exactly? A disease? A disorder? A driving-based video game? Actually, it's none of these things (well, there is a video game but that's not what we're discussing here).

Burnout is the phenomenon where an individual's health (physical and mental) and functionality suffers due to them experiencing excessive stress for extended periods, specifically from their job. As such, it's officially classed as an 'occupational phenomenon' (see 'What is burnout?', p41).

There are those who may scoff at this. After all, hard work never hurt anyone, right? It's character building! You've got to work hard if you want to succeed. You don't get something for nothing, etc. Overall, there are many societal factors and assumptions that can, and do, lead people to assume that constant hard work only has positive outcomes.



ABOVE Experiencing stress for prolonged periods can have dramatic effects on your physical and mental health

The data tells a very different story, however. The reason burnout is mentioned so often is because surveys (conducted in the US) reveal that, pre-pandemic, 43 per cent of workers reported experiencing some form of burnout. Nearly half of the entire workforce.

Alarmingly, yet predictably, the pandemic's made things worse. The same studies conducted post-2020 reveal that 52 per cent of employees, a 9 per cent increase, now report experiencing it. So burnout now affects over half the workforce. Particularly younger employees, who have many more working years ahead of them; those closer to retirement, in more senior positions, with more savings, report less burnout. But even they're feeling the pinch of the pandemic.

Why, though? Given everything we're led to believe about the benefits of hard work, why is burnout such a problem?

STRESS AND ITS IMPACT ON HEALTH

A persistent cause of poor health in modern, developed-world humans, is stress. While we're all familiar with stress, its long-term effects are more profound than most realise, leading to many health problems.

Stress is part of our body and brain's defence system. It's essentially a precursor, a build-up stage, to the more potent, but shorter lived, fight-or-flight response. When we encounter things that we perceive as threats (or potential threats), we experience stress. Which has health consequences, often due to the constant presence in our systems of stress chemicals, such as cortisol.

Physically, stress negatively affects our blood pressure, respiration, weight, immune system and more. Mentally, stress can negatively affect our focus, memory, mood and cognition. Stress is also believed to be a key factor in the onset of both depression and anxiety.

It's well established that burnout causes genuine physical illness, increased feelings of hopelessness or despair, irritability, impatience, and damages relationships with family, friends and co-workers. Burnout can even lead to problems with executive functioning (our ability to think and self-regulate), attention and memory. Overall, burnout mirrors the consequences of excessive stress. It's not just severe exhaustion (although that's a key part of it). However, burnout is specifically a consequence of stress induced by someone's work, their job (see 'What does burnout do to us?', p42).

"GIVEN EVERYTHING WE'RE TOLD ABOUT THE BENEFITS OF HARD WORK, WHY IS BURNOUT SUCH A PROBLEM?"

So, what's so special about work stress?

Much modern adult stress comes via the workplace. Psychologically speaking, there are many things about work that reliably trigger stress in the brain, things that we're less likely to encounter outside of work.

For instance, the human brain likes a sense of control, of autonomy. When we feel we have control over things that affect us, we tend to feel better, more reassured. Most jobs involve adhering to a strict schedule, however, or taking instructions from someone more senior. And in big organisations, it's often hard to understand the logic or rationale of the things you're being made to do. This loss of autonomy is a reliable cause of stress. As is uncertainty, a constant issue when you don't understand why you're being made to do what you're doing.

Humans are also very status-conscious; we instinctively want to be looked up to, respected, approved of. Accordingly, losing status is very stressful. So, constantly being at the mercy of higher-ups or beholden to customers/clients – that causes stress.

GETTY IMAGES X3

Another thing our brains dislike is wasted effort. We have complex neurological systems that assess whether tasks are worth doing, compared to the potential reward they'll produce. Accordingly, if we put more effort in than the reward warrants, that can be a very stressful experience. Say you work for months on a project, only for a boss to suddenly cancel it on a whim. This induces considerable stress.

Of course, not every job is a recipe for constant stress. There are many jobs that regularly rank highly in terms of satisfaction and employee happiness. And, big surprise, they invariably involve a high level of responsibility, autonomy, tangible outcomes for efforts made and appreciation.

Most other jobs struggle to offer such things, though, so they involve more stress. And if you're wondering why people persist in doing them, it's because we need jobs for money and we need money to survive. 'Not surviving' is an even greater stress, so not having a job can be even more stressful than having one you don't particularly enjoy.

Given all this, it's hardly surprising that burnout is as common as it is.

A 'MEDIC' PROBLEM?

Whenever you hear about burnout, it's often in the context of the field of medicine. There are reasons for this; medicine is an extremely demanding, complex and often under-resourced field, and the one workplace where your decisions and performance can literally mean life or death. It's no wonder that burnout among medical staff gets the lion's share of attention.

This is especially valid in the context of the pandemic. Surveys suggest that as many as a third of all medical trainees feel burnt out to a high/very high degree, a significant increase on the numbers pre-pandemic.

Someone regularly dealing with this is consultant paediatrician Dr Serena Haywood, guardian of safe working hours and health and wellbeing champion at St George's NHS Trust.

"Burnout has always been a part of doctors' lives. We accept that stress is part of the job. Every headline screams about ambulance waiting times, patients stranded in A&E and stretched waiting times, and that's an average Tuesday. Much of the time we do what we can and enjoy a challenge knowing that we're ridiculously privileged to work in a career that still is one of the most highly respected and fulfilling. But with one in four people vulnerable to mental health difficulties, a tendency to perfectionism and a drummed-in sense of accountability for everything, doctors can get mired down and exhausted". ➊

ABOVE The demands and nature of the work make burnout an occupational hazard for healthcare workers

WHAT IS BURNOUT?

Given how it's often spoken about as if it is one, it may be surprising to many to learn that burnout is not actually regarded as a medical illness or clinical condition. The World Health Organization (WHO) classifies burnout as an occupational phenomenon.

Burnout is included in the International Classification of Diseases – Volume 11 (ICD-11), the official text produced by the WHO that lists all official health problems known to medicine. However, burnout is listed in 'Factors influencing health status or contact with health services', which focuses on things that can lead to serious health problems, but which aren't medical problems in themselves. Burnout technically has more in common with car accidents and sports injuries than viruses and mental disorders.

This isn't to say that burnout isn't a serious problem. After all, nobody would deny that someone involved in a car crash doesn't warrant medical attention. But equally, few would argue that 'car crashes' are a medical condition. Rather, they're an unfortunate health-endangering consequence of how the modern world works. And the same can be said for burnout.

ABOVE Some of the earliest recorded cases of burnout were seen in air tra ic controllers

Indeed, when the concept of burnout was first established in the 1970s, it was said to be particularly pertinent to 'caring' roles, such as medicine.

One explanation for this would be that humans are very empathetic; we don't just recognise other people's emotional state, we share it, we experience it ourselves. So, when you're already emotionally invested in other people's wellbeing (as those who willingly work in medicine must logically be, to some extent), being surrounded by the sick, infirm and suffering, will directly affect your emotional state, and cause your brain to be more stressed in dealing with it all.

Thus, burnout becomes more likely. Indeed, research suggests that those who display greater empathy are prone to more severe burnout.

However, the data presents a more nuanced picture. The first officially documented cases of burnout came from air traffic controllers. An important and often stressful job, no doubt. But, given how remote much of it is, one that doesn't quite fit the definition of a 'caring' role.

With burnout now an established and well documented phenomenon, there are many ways to identify and assess it, with tools such as the Maslach Burnout Inventory (MBI), which has several variations, with ones for general use, medics, students, educators, and so on. This reveals an understanding that burnout is far from restricted to the medical field.

But given how we're currently so dependent on healthcare workers of all types, and increasingly aware of the pressure they're under, their burnout warrants the most attention.

It can seem like burnout is a modern phenomenon, but as we've seen, it's been recognised for over 50 years at this point. Is it more common

"THOSE WHO DISPLAY GREATER EMPATHY ARE PRONE TO MORE SEVERE BURNOUT"

WHAT DOES BURNOUT DO TO US?

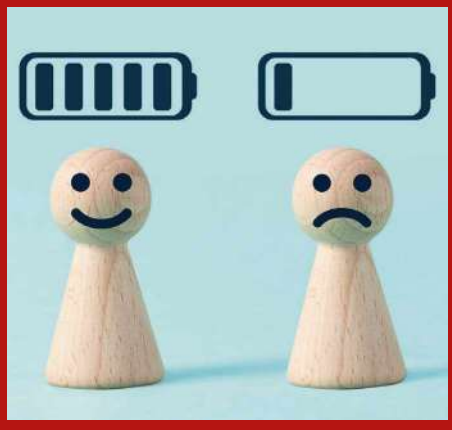
The World Health Organization (WHO) characterises burnout as having three distinct dimensions:

- Feelings of energy depletion or exhaustion (hence many who experience burnout complain about being severely lacking in motivation and energy).
- Increased mental distance from one's job, or feelings of negativism or cynicism related to one's job (those experiencing burnout invariably find that they care less about their jobs and the outcomes of their work, or even start to resent it).
- Reduced professional e icacy (experiencing burnout means you're less able to do your job well).

There's only one recognised form of burnout, but the causes and manifestations vary considerably. The WHO defines burnout as "a syndrome conceptualised as resulting from chronic workplace stress that has not been successfully managed". More simply, burnout happens when your job becomes too stressful over too long a period.

But because stress is so subjective, and every job has the potential to create prolonged and unresolvable stress for employees, burnout can occur in any workforce, for many reasons. And that's why it can seem so variable.

Remember, burnout is specifically described as an occupational phenomenon. O icially, burnout is only ever a consequence of workplace stress. It's entirely possible for your health to su er from stresses that occur outside of work, but this wouldn't be classed as burnout.



ABOVE Depending on the person and their circumstances, simple measures such as getting out and spending some time in nature can help alleviate the symptoms of burnout

these days, though? Perhaps. A growing population means there are more people in the workplace than there were in the 1970s, so, logically, you'd expect to see more burnout as a result. We're also more 'aware' of the condition now, just as we are with health matters in general. Being better able to recognise burnout means we'll find more cases of it.

And maybe the nature of work has changed too, in ways that increase the odds of burnout. Sure, 'old school' jobs, such as coal miner or soldier, were considerably more dangerous than more modern examples. But they were also much simpler, more straightforward and tangible. The complex, unpredictable nature of modern work, often customer-facing or with confusing and abstract instructions and outcomes, may be better at exploiting the weaknesses of the human brain, when it comes to experiencing stress and burnout.

COPING STRATEGIES

So how do we deal with burnout? Well, there are many things to consider. The most obvious option is to try to change your work situation, by talking to superiors and addressing the issues that are causing you so much stress. However, not every workplace has the flexibility, the resources or, sadly, the understanding to do this successfully.

Finding support elsewhere is also an option, be it friends, family or co-workers. Remember, burnout is heavily intertwined with stress and stress is a surprisingly subjective phenomenon. This means that, as facile or twee as some may find it, advice such as 'get more exercise', 'take up a new hobby', 'meditate', 'try mindfulness' and so on, can make a genuine difference in helping people deal with burnout.

Haywood, who does resilience training for healthcare workers, explains.

"I teach that resilience is about learning to fight another day. Learn your rights and responsibilities and escalate concerns. Make sure you remember what it is that you used to enjoy doing before you seemingly worked all hours. Make an apple crumble. And be nice to people, goddammit! One trainee said it was mostly 'woo' but there was one bit of it that was her kind of 'woo'."

The human brain is incredibly powerful, but also complex and, most importantly, finite. Work is a big part of our lives and, especially during the pandemic, a more stressful one. Increasingly often, that stress becomes more than our brains are able to process, leading to burnout. Ultimately, anything that reduces that stress, as long as it's not harmful itself (for example, excessive drinking), can help prevent it. **SF**

by **DR DEAN BURNETT** *(@garwboy)*

Dean is a neuroscientist, science writer, occasional comedian and all-round 'science guy'. His latest book is Psycho-Logical: Why Mental Health Goes Wrong – And How To Make Sense Of It *(£9.99, Guardian Faber).*

A VACCINE FOR CANCER

The pandemic derailed a lot of medical research. But the effort that was suddenly redirected towards developing a vaccine for COVID-19 may have helped us make important progress on at least one breakthrough: preventing cancer

BY DR HELEN PILCHER

In December 2019, Dr Vinod Balachandran and his team had just recruited the first patients for an exciting clinical trial that was happening in New York. It was to test a new type of vaccine for pancreatic cancer. The vaccine, made from a molecule called messenger ribonucleic acid (mRNA), was designed to prime the patients' immune systems to attack their cancer cells, but before the trial could get into full swing, disaster struck. A novel virus, discovered in China, was silently spreading around the globe. Three months later, New York was in lockdown.

With a lot of routine cancer treatment paused, trial participants were understandably nervous. "Patients didn't want to travel to New York," says Balachandran, who is based in the city's Memorial Sloan Kettering Cancer Center. Then there were logistical issues. Biopsy samples taken from the participants had to be sent to a biotech company in Germany for analysis, and the vaccine, which was then tailor-made for each patient, had to be promptly sent back. With many routine flights grounded, it seemed like a tall order, but perhaps the biggest hurdle facing the trial was the fact that the German biotech company they were working with, BioNTech, now found itself embroiled in a race to produce the world's first vaccine for COVID-19.

In the year that followed, BioNTech collaborated with another company, Pfizer, to produce more than 20 candidate COVID-19 vaccines, all made from mRNA, including the one that went on to be given to hundreds of millions of people. It's fair to say that 2020 was a busy year for BioNTech, so you'd be forgiven for presuming that the trial for the cancer vaccines fell by the wayside, but that wasn't the case.

"THE VACCINE WAS DESIGNED TO PRIME THE PATIENTS' IMMUNE SYSTEMS TO ATTACK THEIR CANCER CELLS"

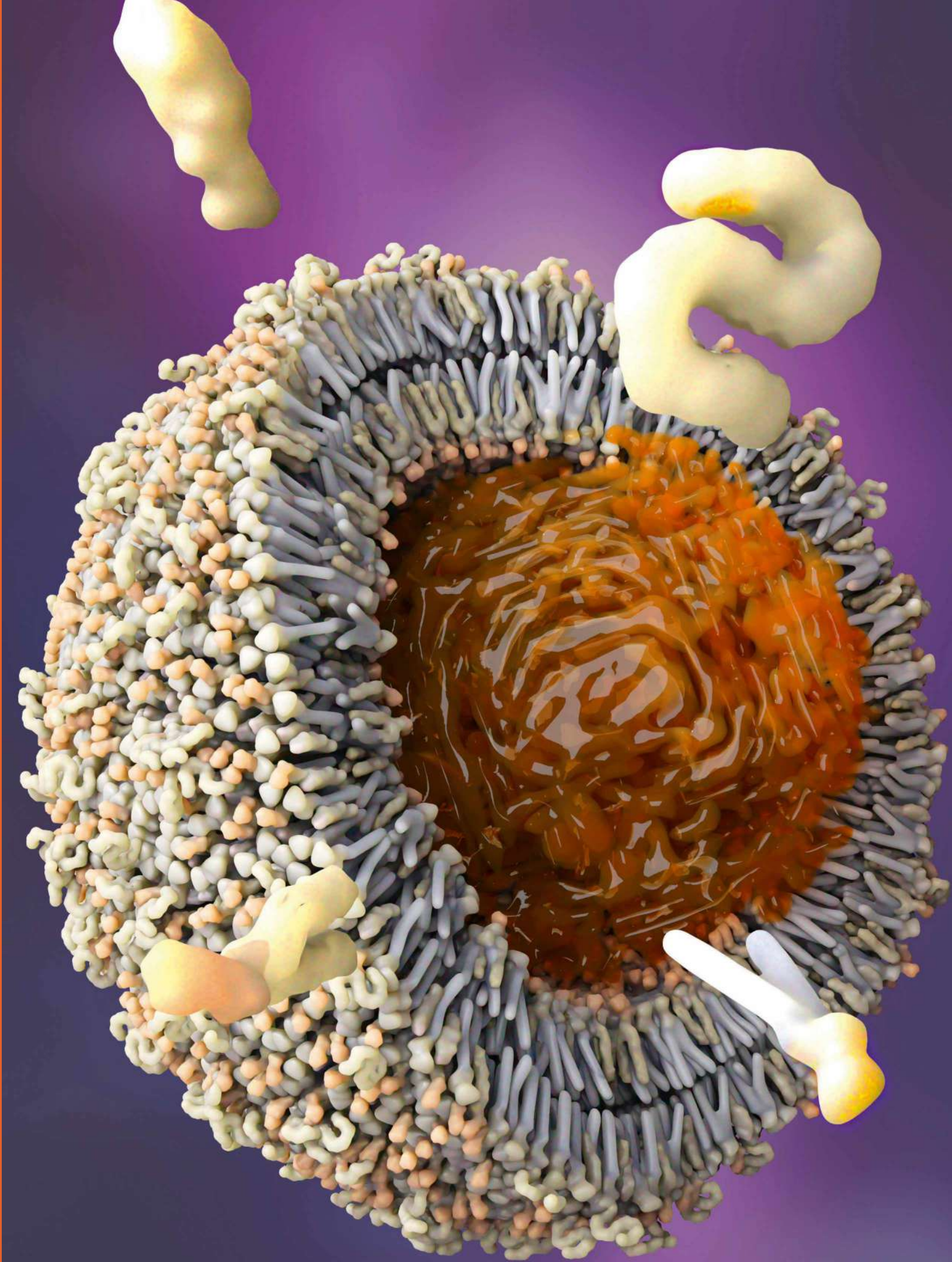
BLESSING IN DISGUISE

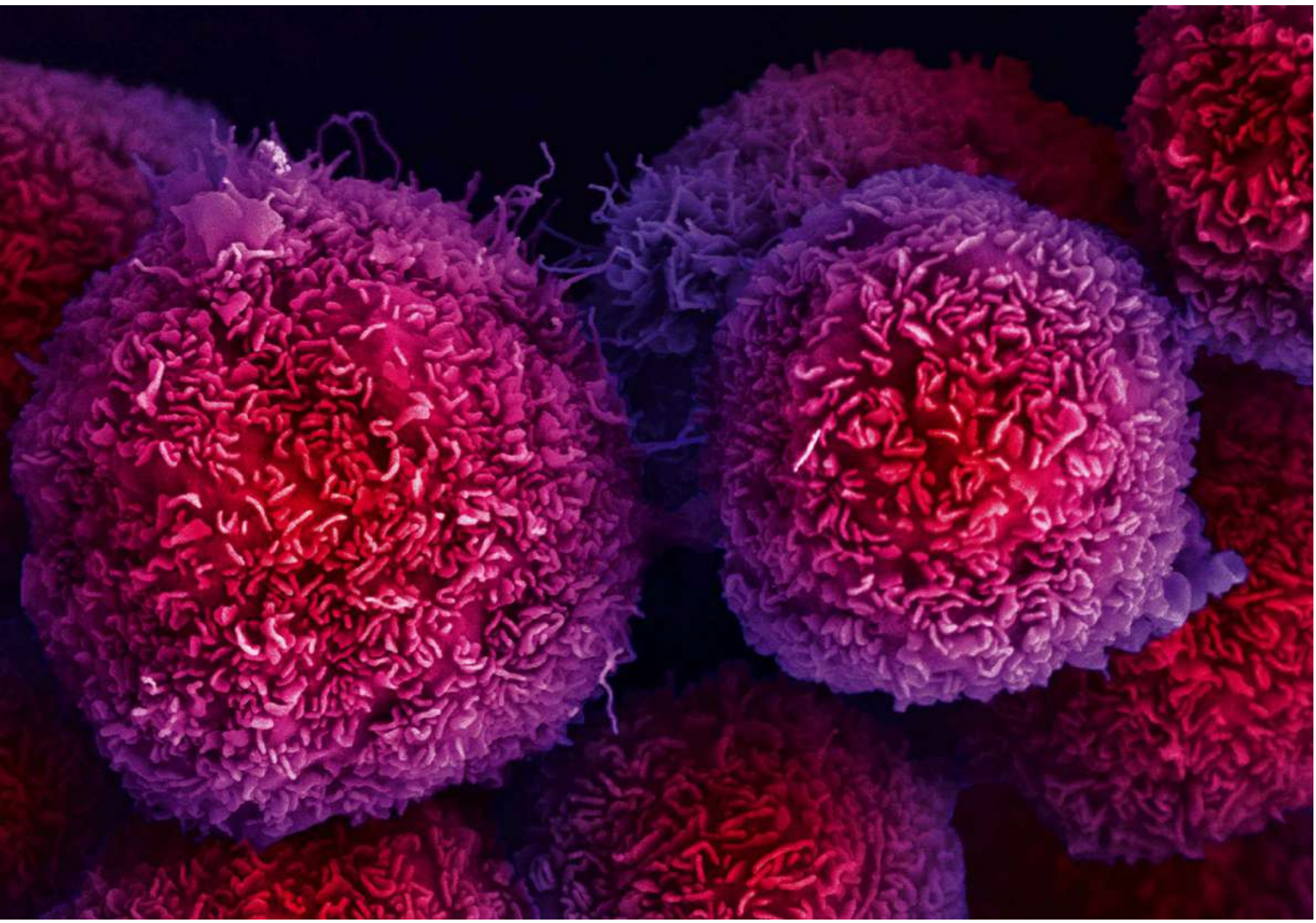
"Instead of slowing the trial down, we actually accelerated it," says Balachandran. Balachandran managed the patients, BioNTech made the cancer vaccines, and a trial that was originally scheduled to take two and a half years, was completed in 18 months.

Counterintuitively, the diversion that threatened to derail BioNTech's involvement in the cancer trial – the rapid production and roll out of an mRNA vaccine for COVID-19 – may actually have been a blessing. Before the pandemic, few people had heard of mRNA vaccines. Investors were disinterested and many scientists were sceptical because mRNA is a notoriously unstable molecule. To top it all, no vaccine of this type had ever been authorised for use. It took a global pandemic and the release of not one, but two mRNA vaccines (from Pfizer/BioNTech and later, Moderna), to prove that these vaccines are safe and that they work.

As a result, mRNA vaccines are generating quite a buzz. They're exciting because they have the potential not just to prevent disease, but in some cases, to treat it. And because they can train the immune system to recognise problem proteins and cells, as well as problem viruses

SCIENCE PHOTO LIBRARY





ABOVE
Pancreatic cancer cells seen under a coloured scanning electron micrograph

SCIENCE PHOTO LIBRARY, GETTY IMAGES

and bacteria, they have the potential to target not only infectious diseases, such as COVID-19 and malaria, but also some non-infectious diseases, such as cancer and multiple sclerosis (see 'Where else could mRNA vaccines work?', p49).

SOME ASSEMBLY REQUIRED

mRNA vaccines are fundamentally different to conventional vaccines. Most regular vaccines work by delivering either a dead or inactivated version of a pathogen, or a protein from that pathogen, into the body. Immune cells in the body recognise key proteins in the vaccine, known as antigens, priming the immune system to respond quickly if it later encounters the pathogen for real.

Vaccines like this can take months to make because the viruses have to be grown inside chicken eggs or mammalian cells. Then, when new strains or variants crop up, the vaccine-making process has to start over.

In contrast, mRNA vaccines are made from a type of genetic code. The code exists as a molecule that occurs naturally in the body, where it directs the production of proteins, and when lab-made mRNA is injected into the body, it does exactly the same thing. Specific proteins are produced, and an immune response can be triggered. The mRNA inside the Pfizer/BioNTech COVID-19 vaccine, for example, directs the body to produce the spike protein that surrounds the coronavirus. There's no need for chicken eggs or cell cultures, because the process relies on the body to assemble the antigens.

"The body is the best manufacturing facility that we have," says Dr Lucy Foley, the director of biologics and COVID response at the Centre for Process Innovation in Darlington, in the north of England. Experimental vaccines can be generated in just one week and because the sequence of the RNA molecule can be easily tweaked, existing vaccines can be altered with ease. This is useful, for example, when new variants of a pathogen evolve. "It's a great platform technology," she says.

In themselves, cancer vaccines are nothing new. Since it was first introduced in England in 2008, the human papillomavirus (HPV) vaccine has led to an 87 per cent reduction in cervical cancer. Similarly, immunisation with a vaccine against the hepatitis B virus (HBV) can help to protect people against liver cancer. Both of these non-mRNA vaccines work by targeting cancer-

causing viruses, but most cancers aren't caused by viruses. This is where mRNA vaccines for cancer can make a difference. By training someone's immune system to recognise tumour antigens, rather than viral ones, mRNA vaccines offer the potential to target a much broader range of cancers.

The problem, however, is that cancer cells are notoriously good at hiding from the immune system, which makes designing the vaccines tricky. In addition, cancer comes in many guises. Breast cancer is different to lung cancer, which is different to melanoma, and no two breast cancers or lung cancers or melanomas are the same. Put simply, everyone's cancer is unique. "Every patient's cancer contains mutations that are particular to them," says Balachandran, so one approach is to make vaccines that are personalised to each patient.

"AN ALGORITHM IS USED TO PREDICT WHICH DIFFERENCES WILL PRODUCE THE STRONGEST IMMUNE RESPONSE"

It's a far cry from the mass-produced 'off the shelf' vaccines that are used against COVID-19 and seasonal flu. After complex surgery to remove their patients' pancreatic tumours, the team in New York sends samples of the cancerous tissue and healthy blood to the BioNTech laboratories in Mainz, Germany. The DNA inside these samples is then deciphered, or 'sequenced', and the genetic codes are compared. Key differences are identified between the diseased and healthy tissue, and an algorithm is used to predict which of these differences will translate to produce the strongest immune response. "Essentially, we're asking, how different are the mutations in the cancer cells from the healthy tissue?" says Balachandran.

The top 20 candidates are identified, and their corresponding mRNA sequences are then used to form the basis of the vaccine. By including 20 different mRNA sequences in the mix, the vaccine is designed to teach the recipient's immune system to recognise not one, but 20 different antigens, boosting the chances that the vaccine will be successful.

Meanwhile, as the vaccine is being assembled in Germany, the patient in New York receives a dose of a drug called a checkpoint inhibitor, which is used to boost their body's

The vaccine against the human papillomavirus is estimated to have prevented 450 cervical cancers since its introduction in the UK in 2008

immune response to cancer cells. Then, nine weeks after undergoing surgery to remove the tumour, the vaccine arrives in the Big Apple, and each patient receives their own bespoke version, delivered deftly into their arm.

GLIMMERS OF HOPE

Balachandran's is one of a growing number of early phase clinical trials seeking to assess the safety and tolerability of mRNA vaccines for a wide range of cancers, including those affecting the ovaries, brain and lungs. Glimmers of hope can be seen. A 2017 study of a personalised mRNA vaccine for advanced melanoma, for example, showed that it reduced the risk of the cancer spreading. "It's too soon to talk about efficacy in our trial," says Balachandran, "but I'm optimistic." Pancreatic cancer has the lowest survival rate of all common cancers. Around 90 per cent of people who have it die within five years of diagnosis, because their cancer keeps coming back. By priming the immune system to destroy any cancerous cells that do occur, the hope is that both remission and life will be longer.

Elsewhere, other mRNA vaccines are seeking to exploit the similarities that exist between different people's cancers, rather than the differences. People with a type of breast cancer known as HER2-positive, for example, are often treated with an antibody-based drug called Herceptin. The treatment can work well initially, but then the cancer cells evolve resistance to it and the drug stops working. It's similar to the way that bacteria develop resistance to antibiotics, only here the cancer cells evolve in a very predictable manner. Specific mutations crop up in specific genes.

Dr Herbert Kim Lyerly from Duke University has designed an mRNA vaccine that targets four of these known mutations, and in 2022 it will be tested in a small number of patients with advanced HER2-positive breast cancer. Every patient will receive the same vaccine because every one of them is expected to develop the same key mutations. "We'll effectively be vaccinating people against mutations that their cancer doesn't yet have," explains Lyerly.

Then, when cancer cells with the mutations do appear, as is highly likely, the patients' immune systems should be ready to hunt them down and destroy them. If it works, the vaccine will prevent their cancer from evolving resistance to Herceptin, so a drug that works well initially, can continue to work well indefinitely. "The hope would be that you would never run out of treatment options," says Lyerly.

This isn't just 'treating' cancer, it's anticipating and then preventing cancer. As more becomes known about the genetic progression of different cancers, it's entirely conceivable that the same approach could be applied to other cancers too.

Suppose someone has a family history of a particular cancer, or genetic tests reveal that they have a heightened risk. If the genetic hallmarks of that cancer are predictable and well known, and if the technology is available, then an mRNA vaccine could be used to prime their immune system to destroy the cancer at source. "My gut feeling is that the technology is moving in this direction," says Dr Samuel Godfrey, the

ABOVE Dr Vinod Balachandran, whose cancer vaccine trial took place during the height of the COVID-19 pandemic

ABOVE LEFT Balachandran and colleagues analyse data generated during the cancer vaccine trial

MEMORIAL SLOAN KETTERING CANCER CENTER, GETTY IMAGES X3

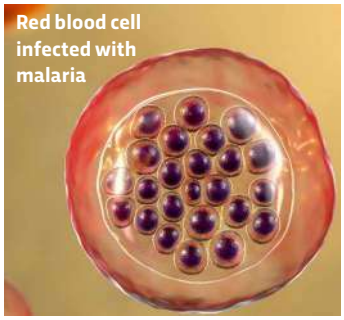
senior science communications manager at Cancer Research UK.

There are caveats of course. Many promising early-stage treatments flounder the more they're tested, and Godfrey points out that a vaccine or treatment that works for one person may inexplicably fail for another. Nor is the Holy Grail of cancer therapy – a single shot to prevent all cancers – likely to happen. Cancer is a diverse collection of diseases that is far too complex to be beaten by a single approach. More likely then, is that if mRNA vaccines prove their worth in clinical trials, they'll go on to be used alongside other therapies, such as antibodies, surgery and chemotherapy.

Nevertheless, the promise of mRNA vaccines, not just to treat certain cancers, but also to prevent them, remains firmly on the cards. "We're getting to a point where we can start to be proactive with cancer as well as reactive to it," says Godfrey. "I think it's phenomenally exciting." **SF**

by **DR HELEN PILCHER**
(@HelenPilcher1)
Helen is a tea drinker with a PhD in neuroscience, and the author of Small Inventions That Made A Big Difference *(£14.99, Wellbeck).*

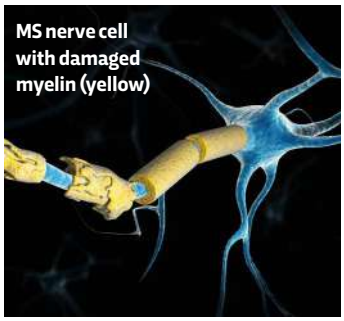
WHERE ELSE COULD mRNA VACCINES WORK?


Red blood cell infected with malaria

Malaria

In 2021, the World Health Organization approved the first mass rollout of a vaccine for malaria, but it's far from perfect. Although it is not an mRNA vaccine, it reduces disease severity and prevents cases in around 40 per cent of people.

A key problem with making a malaria vaccine is that the parasite responsible for the disease has evolved a way to prevent the immune system from remembering it. Richard Bucala, professor of medicine, pathology, and epidemiology and public health at the Yale School of Medicine, has shown the involvement of a key parasite protein, called PMIF, which suppresses the host's immune system and prevents it from making key immune cells. Working with the drug company Novartis, Bucala has developed an mRNA vaccine that targets this protein, and which has been shown to help protect mice against malaria infection. Now Bucala has joined forces with scientists at Oxford's Jenner Vaccine Institute, and they hope to test the vaccine in people later this year.


MS nerve cell with damaged myelin (yellow)

Multiple Sclerosis

Multiple sclerosis (MS) occurs when the body's immune system malfunctions and starts destroying the fatty myelin coating that surrounds nerve cells. With assistance from BioNTech, German researchers have devised an mRNA vaccine that encourages the immune system to tolerate the myelin protein, rather than attack it. Research published in 2021 showed that the vaccine delayed the onset and lessened the severity of an MS-like disease in mice.

It's an encouraging result. Current MS treatments work by targeting the immune system as a whole, which means the drugs often cause side e ects. The mRNA vaccine, in contrast, is designed to target only those cells that attack the myelin, so side e ects could be minimised. It's early days, though, and there are, as yet, no clinical trials for MS mRNA vaccines in patients.


Rendering of HIV virus

HIV

It's not easy to make an HIV vaccine because the virus mutates quickly, so it's hard to find a stable target for a vaccine. But Dr Derek Cain from Duke University has shown that some patients with chronic HIV develop antibodies that can neutralise the virus. Unfortunately, the antibodies do little to help the patients because there's already too much virus in their bodies, but if an HIV-free person could produce the same antibodies, it might help protect them from future infection. Last year, a vaccine based on this idea was tested in a small human trial. In total, 97 per cent of those who received the vaccine produced the immune cells needed to generate the antibodies. "This study demonstrates proof of principle for a new vaccine concept for HIV," says Dr William Schief, who worked on developing the vaccine.

GATEWAY TO THE FUTURE

2022 will see NASA, with help from its international partners, take the first major step on humanity's journey back to the Moon, and the start of a mission to establish an outpost alongside Earth's natural satellite

BY DR STUART CLARK

If all goes to plan, sometime in 2022 NASA's Space Launch System rocket (SLS) will blast off from Cape Canaveral, Florida, for its maiden flight. The giant SLS rocket, fully 111.25m tall, is set to launch no earlier than February, but probably not until the summer, and will send an uncrewed capsule on a test mission around the far side of the Moon and back again. Known as Artemis 1, it will truly mark the beginning of humanity's return to the Moon.

The Artemis 2 mission, currently scheduled for May 2024, will repeat Artemis 1 but this time with a crew of astronauts. In their looping journey around the Moon, they'll go further into space than any previous astronaut. Then comes the big one: Artemis 3, which will carry the next astronauts to land on the Moon.

In between these tent-pole missions will be a sequence of other launches to ensure the astronauts have everything they need to complete their missions when they reach lunar orbit. Absolutely critical to the long-term success of the Artemis programme is the Gateway lunar space station.

Gateway will be a multi-module space station in orbit around the Moon. It will act as a staging post for visits to the lunar surface, provide an orbital platform from which to conduct remote observations of the Moon and provide laboratories to analyse Moon rocks and conduct other scientific studies. It's an international effort between the US, 10 European countries, Canada and Japan.

It may sound like science fiction, but it's very real. And very, very cool...

NASA/ALBERTO BERTOLIN

THE SCIENCE

Gateway will act as a temporary home and workspace for astronauts visiting the Moon, much like the International Space Station does for astronauts visiting low Earth orbit. During the initial exploration of the Moon, astronauts will live on Gateway for up to three months, occasionally travelling down to the lunar surface to conduct science or test devices that will allow them to set up a permanent base on the surface.

Two experiments that have already been commissioned for Gateway are a radiation monitor supplied by the European Space Agency (ESA) and a space weather instrument suite. The radiation monitor will help decide how to keep astronauts safe from unhealthy levels of radiation that can be encountered in space. The space weather instrument suite is related to this because it will measure the intensity of particles released by the Sun during outbursts called coronal mass ejections.

A big focus will be on developing the technique of in-situ resource utilisation. This means using resources found on the Moon to manufacture things that the astronauts will need, for example, water, oxygen, rocket fuel and building materials can all be extracted or manufactured from materials found on or just below the lunar surface.

THE MODULES

Although smaller than the International Space Station (ISS), Gateway is too large to be launched on a single rocket. Instead, it will consist of a number of modules that will be placed around the Moon in a series of launches.

At its heart is the Power and Propulsion Element being developed by Maxar Technologies in the US. This module uses solar panels to generate power. It can also convert that power into propulsion using a 'solar electric propulsion' unit (or ion engine), to move the station into different orbits.

The Habitation and Logistics Outpost (HALO) module is being supplied by Northrop Grumman Innovation Systems. This will be the first module in which astronauts can live. It will include docking ports for the Orion spacecraft carrying the astronauts.

Together these two modules form a workable initial station. Although they were initially planned to be launched separately and then docked in space, NASA will now fix the two modules together and fly them on a single launch, scheduled for November 2024 on a SpaceX Falcon Heavy rocket.

This will be the configuration of the Gateway for the Artemis 3 Moon landing mission, but it will soon be joined by modules supplied by ESA. Europe is a major contributor to Gateway and the Artemis missions. Italy, in particular, is a significant partner with a distinguished heritage in space station design and manufacture. Around half the pressurised modules on the ISS were supplied by Thales Alenia Space in Turin.

"That is a great legacy," says Luigi Pasquali, space activities coordinator of Leonardo, the Italian company that jointly owns Thales Alenia Space. It has allowed the company to win the contracts to provide a number of modules for Gateway.

First will be the European System Providing Refueling, Infrastructure and Telecommunications (ESPRIT). This will consist of two parts, the first will be the station's lunar communications system. As this is essential component from day one, it's being manufactured in advance and will be affached to the HALO module for launch in 2024. The second part of ESPRIT will contain additional fuel tanks, a windowed habitation corridor and docking ports. Currently it's scheduled for launch in 2027.

In addition, Thales will also contribute the International Habitation Module (I-HAB), which will contain a life support system supplied by Japan. Finally, Canada is producing an 8.5m-long robotic arm, similar to the one the country contributed to the ISS and Space Shuffle programmes.

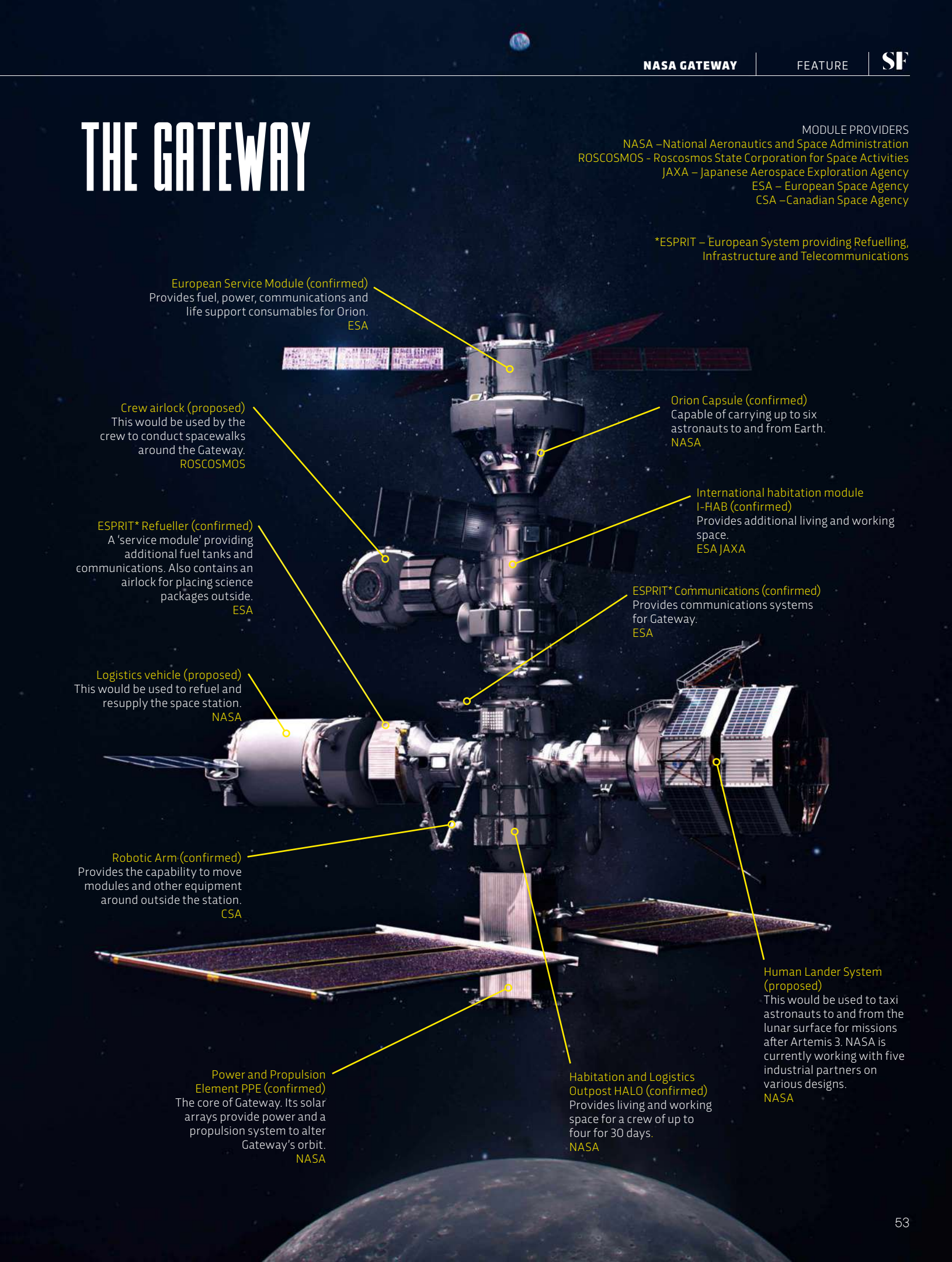
Gateway's HALO module is being supplied by Northrop Grumman

NASA/ALBERTO BERTOLIN X2, THALES ALENIA SPACE

THE GATEWAY

MODULE PROVIDERS
NASA –National Aeronautics and Space Administration
ROSCOSMOS - Roscosmos State Corporation for Space Activities
JAXA – Japanese Aerospace Exploration Agency
ESA – European Space Agency
CSA –Canadian Space Agency

*ESPRIT – European System providing Refuelling, Infrastructure and Telecommunications



European Service Module (confirmed)
Provides fuel, power, communications and life support consumables for Orion.
ESA

Crew airlock (proposed)
This would be used by the crew to conduct spacewalks around the Gateway.
ROSCOSMOS

ESPRIT* Refueller (confirmed)
A 'service module' providing additional fuel tanks and communications. Also contains an airlock for placing science packages outside.
ESA

Logistics vehicle (proposed)
This would be used to refuel and resupply the space station.
NASA

Robotic Arm (confirmed)
Provides the capability to move modules and other equipment around outside the station.
CSA

Power and Propulsion Element PPE (confirmed)
The core of Gateway. Its solar arrays provide power and a propulsion system to alter Gateway's orbit.
NASA

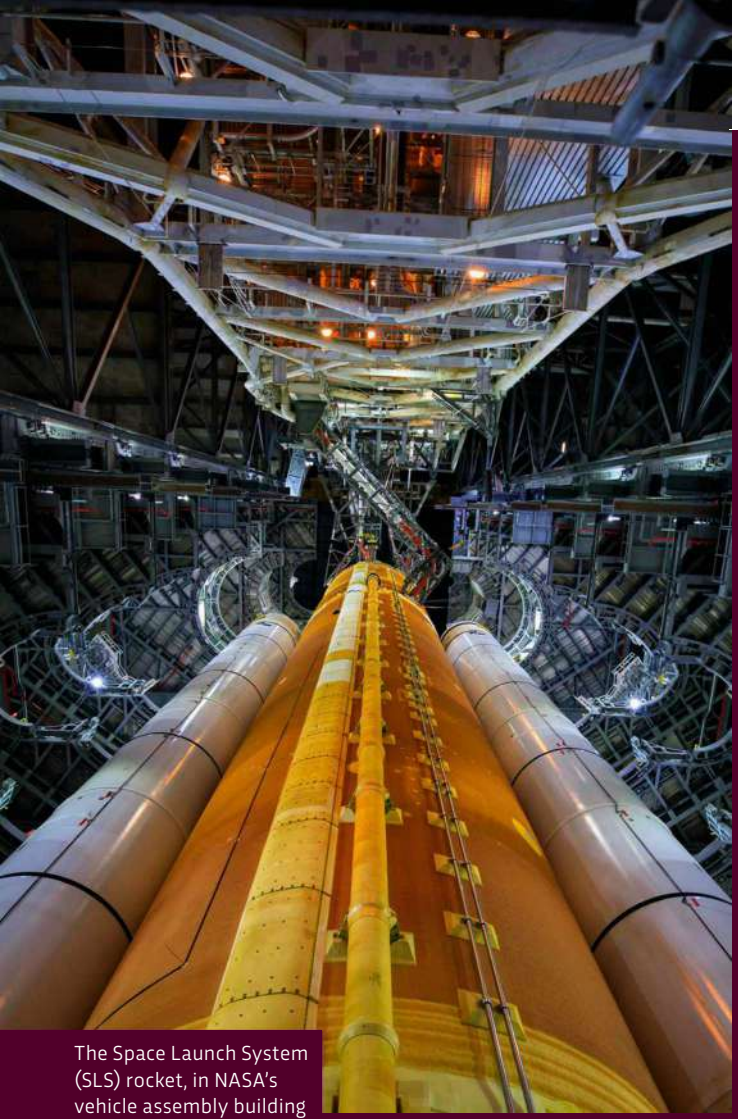
Orion Capsule (confirmed)
Capable of carrying up to six astronauts to and from Earth.
NASA

International habitation module I-HAB (confirmed)
Provides additional living and working space.
ESA JAXA

ESPRIT* Communications (confirmed)
Provides communications systems for Gateway.
ESA

Habitation and Logistics Outpost HALO (confirmed)
Provides living and working space for a crew of up to four for 30 days.
NASA

Human Lander System (proposed)
This would be used to taxi astronauts to and from the lunar surface for missions after Artemis 3. NASA is currently working with five industrial partners on various designs.
NASA



The Space Launch System (SLS) rocket, in NASA's vehicle assembly building

THE SPACESHIPS

Of course, having a space station orbiting the Moon is useless if you have no way of getting astronauts to it. That's where the Orion Multi-Purpose Crew Vehicle comes in. The crew module is being supplied by NASA via Lockheed Martin in the US, and can house up to six astronauts, but the heart of the spacecraft is the European Service Module (ESM) that sits behind the crew capsule. It's being provided by Europe's Airbus company. "ESM provides everything that the astronauts need to live," says Siân Cleaver, who is the Airbus industrial manager for the ESM.

The ESM is based on the Automated Transfer Vehicle (ATV), also manufactured by Airbus. ATV was one of the European Space Agency's contributions to the International Space Station. It carried cargo to and from the facility in low-Earth orbit. To transform it into the ESM and get it to the Moon, however, requires one very obvious difference.

"It's got a massive main engine on the bottom," says Cleaver.

The first ESM is already on top of the Space Launch System rocket, in preparation for the Artemis 1 mission in 2022. The second has been shipped to Florida for mating to the crew capsule. This will be the first Orion to carry astronauts, on the Artemis 2 mission. Cleaver and colleagues are working on ESM 3, the one that will take the astronauts to the Gateway station, before their descent to the lunar surface.

"It's definitely mind-blowing. I feel very lucky. It was always my dream to work in human spaceflight," Cleaver says.

The astronauts of Artemis 3 will shuttle to the lunar surface inside a SpaceX Starship craft. After that, NASA is beginning to develop a smaller lunar lander for more routine missions to and from the surface.

THE SPACESUITS

To walk on the Moon obviously requires a spacesuit – and these are not simple items of clothing. Spacesuits have constantly evolved to give astronauts the protection and the usability they need. For the Artemis Moon landings, those will have to be taken to a whole new level.

If you think of a spacesuit not as a garment, but as a flexible spacecraft that you wear, then you get closer to the complexity involved in making one. On top of that, it should hinder the astronaut's movements as little as possible.

NASA is designing the eXploration Extravehicular Mobility Unit, or xEMU. A big issue for mobility in a spacesuit is the pressure of the air inside. When an astronaut bends a limb, it compresses the material and reduces the volume inside the suit, leading to an increase in air pressure that resists the motion of the astronaut.

Using bearings at the joints rather than compressible fabric helps address this issue. Whereas the Apollo spacesuits worn by Neil Armstrong and Buzz Aldrin on their trip to the Moon in 1969 used bearings only in the arms, the xEMU will use them in the arms, waist, hips, thighs and ankle joints. The suits will also let the astronauts vary the air pressure, allowing them to reduce it in order to kneel down.

NASA engineer Kristine Davis wears the xEMU suit at its 2019 unveiling

All in all, the new innovations should provide far more flexibility for the astronauts and a much more comfortable environment in which to work. It should even allow them to walk more normally than the Apollo astronauts, who developed a kind of loping gait because of the low lunar gravity combined with the inflexibility of the spacesuit.

It's hoped Gateway will enable us to study and use the resources on the lunar surface

NASA/KSC, NASA/ALBERTO BERTOLIN, THALES ALENIA SPACE, ALAMY

THE LOCATION

Gateway will orbit the Moon on a large elliptical path that will take it over both the lunar north and south poles. It will require almost seven days to complete an orbit. At its furthest, it will be 70,000km away from the Moon, before closing to within 3,000km. The orbit offers easier access to land in the lunar polar regions, especially the south pole, which is thought to be rich in ice deposits. It also offers excellent communications possibilities with Earth because it means Gateway spends very little time being eclipsed from Earth's line of sight.

THE FUTURE

The first thing that Gateway will do is make it easier to establish a permanent base on the Moon. "Gateway has a strategic role in really being able to develop a large presence on the lunar surface," says Pasquali.

This is because it will provide a stable, safe base of operation from which to gradually develop the equipment and infrastructure that will bring a lunar base to life.

"I know, it's really cheesy, but whenever I look at the Moon, I always think about the fact that we're going there soon. And then I look at the spacecraft in the clean room the next day and I think, 'Okay, what I'm doing has a real purpose'," says Cleaver.

And unlike the curtailed exploration of the Moon in the 1970s, this time it's being undertaken with a long-term purpose in mind. In November 2021, NASA confirmed that beyond the Artemis 3 lunar landing, the agency is developing a sustainable programme that envisages at least 10 further visits to the Moon's surface.

And beyond that, Mars beckons. This is one reason why the Orion spacecraft is called the Multi-Purpose Crew Vehicle, to indicate that it has uses other than 'just' travel to and from the Moon.

And being well outside of the protection of Earth's magnetic field, the Gateway also allows the effects of deep-space radiation on the health of astronauts to be fully assessed. Knowledge of this is critical for a journey to Mars, where the cruise time in deep space will be at least nine months.

In short, Gateway is essential to all future exploration. Rather than just getting us back to the Moon, history may look back at it as the gateway to the human exploration of the entire Solar System. SF

by DR STUART CLARK *(@DrStuClark)*
Stuart is an astronomer and journalist with a PhD in astrophysics. He's also the author of Beneath The Night *(£14.99, Guardian Faber).*

COMMENT

RUNNING CIRCLES AROUND DEPRESSION

Lacing up your trainers can help reduce your chances of developing depression

New Year means New Year's resolutions and for lots of people that means taking up running or joining a gym in the hope that this will help them shed the kilos they've piled on over Christmas and the long months of COVID that came before.

I won't be joining them, because I hate the gym and I find that going for a run is nothing but pain, followed by relief when I stop. But I will continue to do brisk walks outdoors and sessions on my bike because I know they're good for my overall health and may also cut my chances of developing depression.

A few years ago I saw a study in the journal *JAMA Psychiatry* where researchers from Massachusetts General Hospital in the US analysed the health records of nearly 8,000 volunteers for a project called the Partners Healthcare Biobank. When they were first enrolled they were genetically tested, and also filled in a survey about their lifestyle habits, which included their level of physical activity.

The researchers found that, over time, people who had a higher genetic risk of depression were indeed more likely to become depressed. But the people who were more physically active, whether they had the higher genetic risk or not, were far less likely to develop the condition compared with those who were less active.

"The researchers calculated that doing four hours of exercise a week cuts your risk of depression by 17 per cent"

The researchers calculated that doing four hours of exercise each week (that is about 35 minutes a day) cuts your risk of becoming depressed by about 17 per cent. And that's regardless of genetic status. The researchers didn't go into why they thought this might be happening, but I wondered when I first read it if at least some of the volunteers were getting a surge in their endocannabinoids, which can contribute to 'runner's high'.

Endocannabinoids are naturally occurring substances produced by your body that are known to have a major impact on sleep, appetite, pain, memory and mood.

A couple of years ago, for the BBC series *Trust Me, I'm A Doctor*, I took part in an experiment with Prof Saoirse O'Sullivan, from Nottingham University, where we looked at the impact of exercise on endocannabinoids. For our experiment, O'Sullivan and her team measured blood levels of endocannabinoids in a small number of volunteers before and after a 30-minute run. They found that the run did indeed boost their levels for several hours afterwards.

I was particularly struck by one of our participants, who said she suffered from severe depression, and found that one of the best ways to control it was with regular runs.

Sadly, when they tested me, there was no surge at all in my endocannabinoid levels after exercising. Which could explain my aversion to running. Despite that, I will keep exercising, but don't expect me to smile. SF

MICHAEL MOSLEY

Michael is a writer and broadcaster, who presents *Trust Me, I'm A Doctor*. His latest book is *COVID-19: Everything You Need To Know About Coronavirus And The Race For The Vaccine* (£6.99, Short Books).

BBC TWO

PORTRAIT: KATE COPELAND ILLUSTRATION: JOE WALDRON

COMMENT

A WHOLE NEW WORLD?

Technology has transformed our lives in the last couple of years. Will it continue to do so as we ring in 2022?

It's the most wonderful time of the year: when columnists pull out their crystal balls and predict what will happen in the next 12 months. I've known several who've kept a running tally of how accurately they predicted the future and, in general, their year-end reviews show that their predilection for predictions fall short of even chance.

But why break with traditions? Here are my four possible ways technology will be interrupted that you can expect to see by close of play 2022.

First, office workers won't have a choice but to go back full-time. The great hybrid rebound that appears to have evolved since lockdowns lessened, will be discarded by year-end. Already, we know that the top brass want their employees back in the office to be able to look them in the eye, but this won't be the catalyst; tax jurisdictions, health and safety concerns and intellectual property will force CEOs to mandate bums on seats, because otherwise, insurance will be too high. So say sayonara to your comfy and casual attire.

Second, we'll soon start to see the spoils of a new crop of entrepreneurs who will launch their internet products. The last two years have accelerated our digital migration and now everyone knows that this internet malarky could bend to our wills, if we just had the right tools.

"Governments around the world will get closer to regulationg the internet"

And now that more people have become empowered by their deeper knowledge of this crazy online world, they've got all creative and started to find their own solutions to fulfil their specific needs. Some of these solutions will work, but a lot of them won't – it's time to test them all out to see who the next Jeff Bezos or Mark Zuckerberg will be.

Third, our battle against the hypnotic screen will continue. Digital detoxing will become a bigger moneyspinner than before. Conscientious people will show up to promote and sell services and tools we can use to do the things we want to do, but without staring into a black mirror while we do it. Brace yourself for a flood of products coming to market next year that make everyday tasks more difficult, but screenless.

Fourth, governments around the world will get closer to regulating the internet. Right now, the online world is an unregulated miasma of QAnon conspiracy theories and questionable black markets. And you know what? Some like it this way. The intangible Wild West will be hauled up in front of even more parliamentary hearings by people who don't understand that the problem isn't the technology but the laws that are already in place – if the regulation only applies to the offline world, this is your fault. We lost control of the line between the virtual and the physical a long, long time ago. The only people who will ultimately notice are ageing digital utopians, libertarians and academics. The rest will happily tap their privacy away into one social network or another just like we've always done.

This year, we'll accept the new digital normal. Our human/tech boundaries will evolve – at times painfully – throughout 2022, as we realise there's no going back. **SF**

ALEKS KROTOSKI

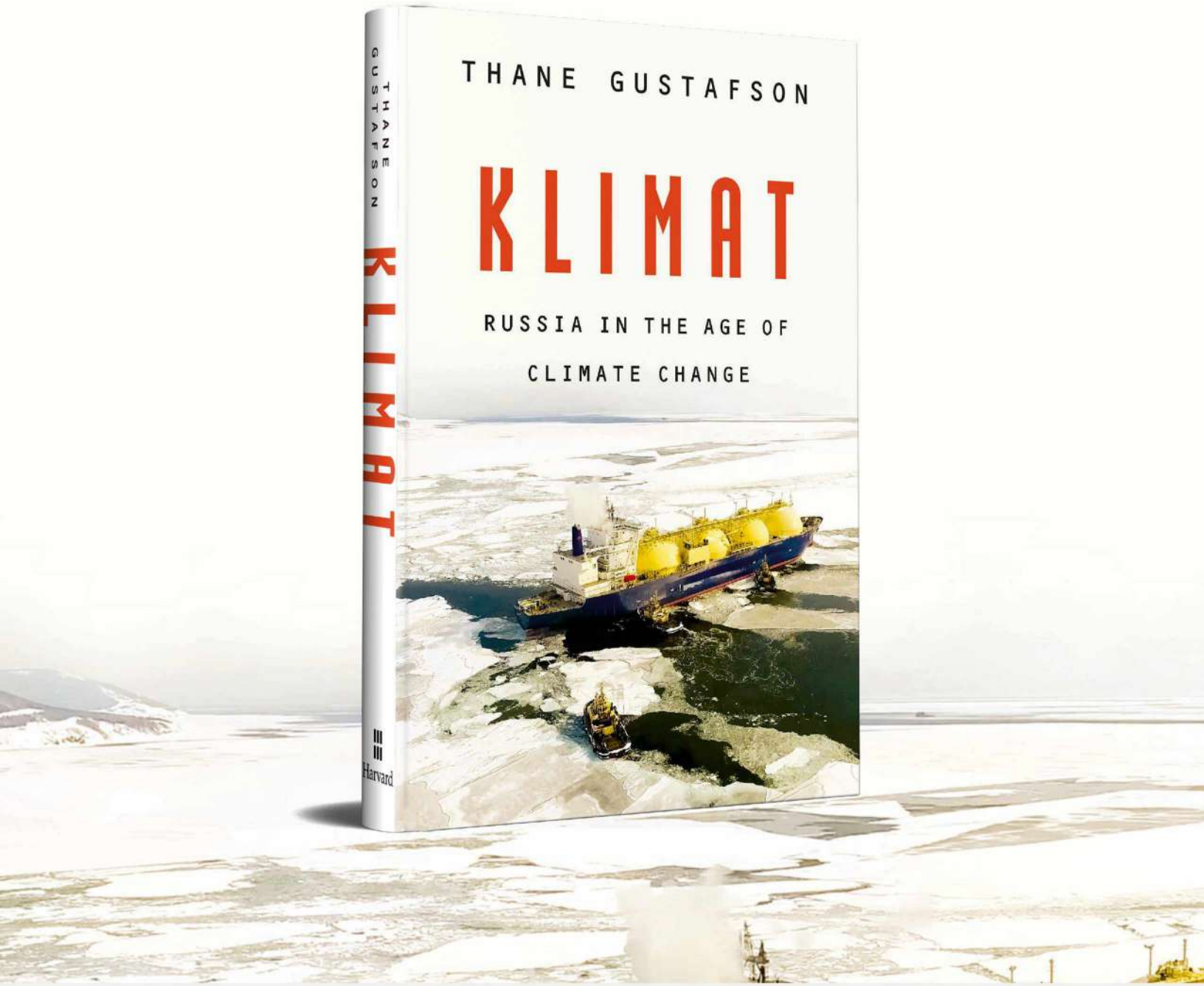
Aleks is a social psychologist, broadcaster and journalist. She presents *The Digital Human*.

BBC RADIO 4 92–95 FM & 198 LW

PORTRAIT: KATE COPELAND ILLUSTRATION: SCOTT BALMER

"A sobering assessment of the impact of climate change on Russia's standing as a great power from one of the most acute observers of environmental and energy issues. Highly recommended."

—Francis Fukuyama, author of *Identity*



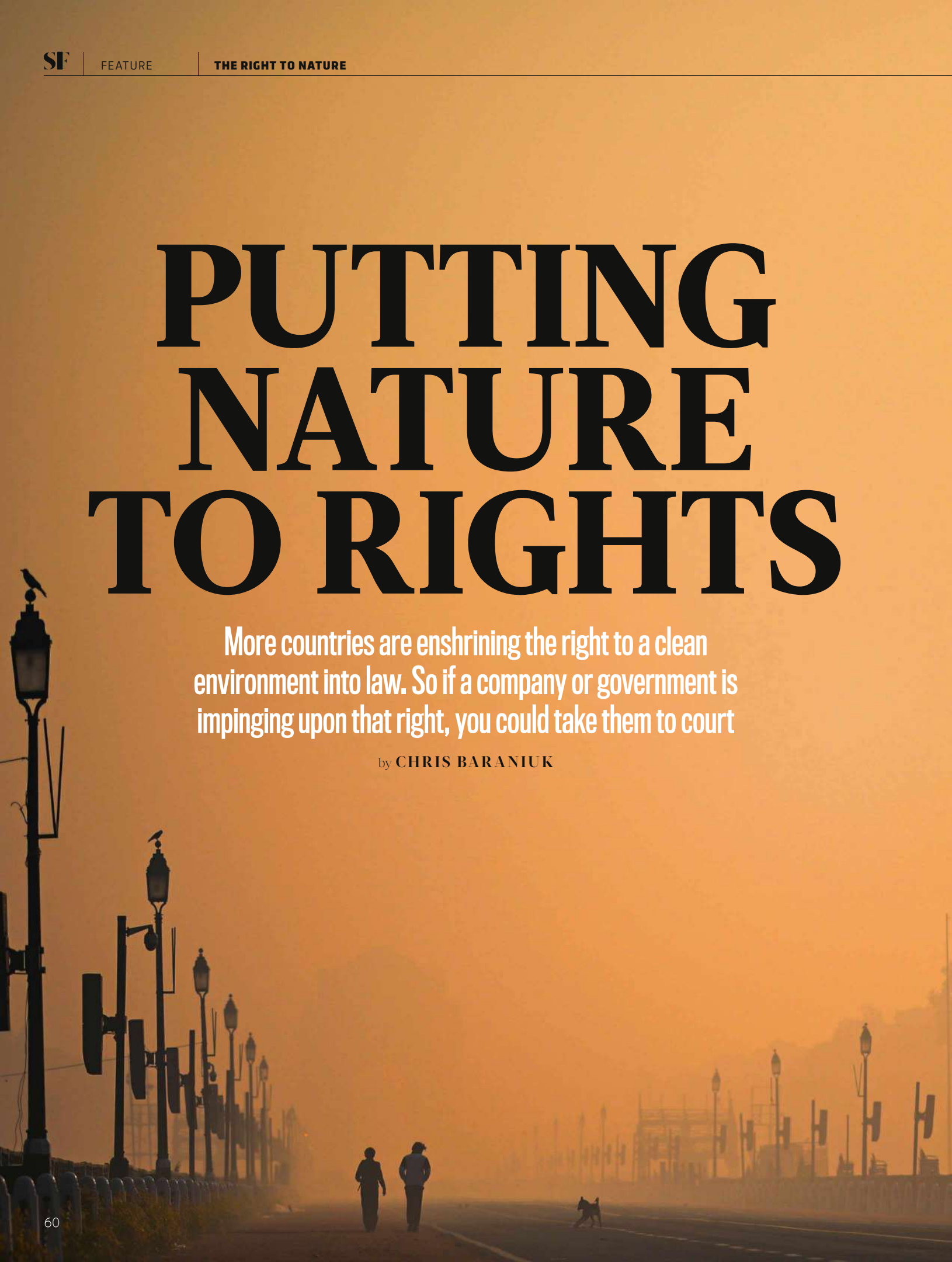
Harvard University Press

hup.harvard.edu

PUTTING NATURE TO RIGHTS

More countries are enshrining the right to a clean environment into law. So if a company or government is impinging upon that right, you could take them to court

by CHRIS BARANIUK



An Asian megacity partially locked down because of pollution. Acres of farms in Africa destroyed by extreme weather. Ancient Arctic cultures disappearing with melting ice.

This isn't the future. It's happening now.

"I have a lot of problems with coughing as soon as I go out of the room," says Mukesh Khare, professor emeritus at the Indian Institute of Technology Delhi. In November 2021 authorities in New Delhi closed schools, temporarily banned construction activities and advised people to work from home. A response to choking smog.

In Africa, extreme weather has become far more common than it once was, from blistering heat and drought to erratic, torrential rainfall and the devastating floods that ensue, says Dr Catherine Nakalembe at the University of Maryland, in the US. "These extreme 1-in-30-year events have become one-in-every-three-year events. People don't have time to adjust."

And in the cultural region of Sápmi, which stretches across parts of Norway, Sweden, Finland and Russia, Saami reindeer herders have told postdoctoral researcher Dr Klemetti Näkkäläjärvi at the University of Oulu in Finland that the threat of climate change is dissuading young people from learning traditional herding techniques. "They fear the effects and the future," one of his sources told him. "If they don't start, then our reindeer herding culture will disappear."

All of these problems and many more besides could be said to reveal the human impact of a degraded environment. Climate change, species loss, sea level rise, pollution and environmental disasters exacerbated by human activity all have the ability to greatly harm people and entire societies. That's partly why, in October 2021, the United Nations' Human Rights Council voted to recognise the right to a safe, clean, healthy and sustainable environment as a human right.

LIVES AND LIVELIHOODS AT STAKE

The number of countries that have recognised the human right to a healthy environment in some way within their constitutions is now well over 100. That has led to more legal action and petitions to governments to take greater steps towards tackling climate change and related issues. "That has been mushrooming all around the world," notes Prof Timo Koivurova at the University of Lapland.

Public awareness of climate change does appear to be growing. A recent YouGov poll in the UK suggested that ➤

"THE NUMBER OF COUNTRIES THAT HAVE RECOGNISED THE HUMAN RIGHT TO A HEALTHY ENVIRONMENT IS NOW WELL OVER 100"

GETTY IMAGES

Two people walk through yellow smog in New Delhi in January 2021

ABOVE Smog engulfed Delhi in November 2021, with air quality falling to hazardous levels

ABOVE RIGHT Of the 17 sustainable development goals established by the UN, number six is 'clean water and sanitation for all'.

RIGHT Urgenda's campaigners outside the Dutch Supreme Court ahead of their landmark victory in 2019

40 per cent of people would list climate change as being among the top three issues facing the country – a proportion that's quadrupled in just three years.

This suggests that people increasingly have the will, and often the means, to take legal action in a bid to protect the environment. Not just because the environment is important, in and of itself, but also because our lives and livelihoods depend on it.

It's partly this idea, that humans can't do without a clean environment, that makes the protection of nature a human rights issue, explains Ben Schachter, human rights officer at the Office Of The United Nations High Commissioner For Human Rights (OHCHR). Clean water, breathable air, healthy ecosystems, a stable climate – they're not just nice things to have. "It's very clear that without these things you can't enjoy other human rights, such as the rights to life, health, development, culture," says Schachter. "That's why we work on the area."

As an example, he notes that disasters related to climate change displace millions of people every year. This figure reached a record-breaking 55 million people in 2020, for example. And according to the World Health Organization, 4.2 million people die annually due to outdoor air pollution.

Schachter stresses that his and his department's role is not to lobby the Human Rights Council for specific action, though it does lobby other parts of the UN on certain issues. In general, the OHCHR is keen to advance the human right to a healthy environment. Schachter says that in 2022, the countries that drafted the Human Rights Council resolution will likely bring a similar resolution to the General Assembly, which is the main policy-making body within the UN.

If that resolution also passes, it will be yet another boost to those people around the world who are taking legal action to protect the environment, says Prof Susana Borràs Pentinat, a lecturer of public international law and international relations at Universitat Rovira i Virgili in Spain.

TAKE IT TO TRIAL

Lawsuits of this kind aren't new, and the concept of a human right to a clean environment is decades old, but legal action in this vein is now gathering greater attention. And becoming more ambitious.

In September 2020, six activists from Portugal (four children and two young adults) filed a case at the European Court Of Human Rights in Strasbourg. They demanded that a total of 33 countries (the member states of the European Union plus other countries including Russia and the UK) make greater cuts to their emissions in an effort

"IT'S CLEAR THAT WITHOUT THESE THINGS YOU CAN'T ENJOY OTHER HUMAN RIGHTS, SUCH AS THE RIGHT TO LIFE"

GETTY IMAGES X2, NASA, UNICEF/GLOBAL GOALS CAMPAIGN

to limit global warming to 1.5°C above pre-industrial levels, or less, as stipulated by the Paris Climate Agreement.

At the time of writing, the case is still in motion, with the activists' legal team due to respond by 12 January 2022, to defences submitted by the governments involved.

In 2019, a case at the Supreme Court in the Netherlands brought by Urgenda, a non-profit, resulted in a win for the campaigners. The court ruled that the Dutch state had to reduce its greenhouse gas emissions by 25 per cent by 2020 compared to 1990 levels. The court explained that its decision was partly based on the fact that "climate change threatens human rights".

Legal efforts to safeguard the environment often rest on the application of rights of one kind or another. And that can have interesting outcomes. In 2018, Colombia's Supreme Court famously granted rights of personhood to the Colombian part of the Amazon rainforest. Various rivers around the world, including in Canada and New Zealand, have also been granted personhood by judiciaries.

"This is a completely new trend in giving nature its own rights," says Prof Malgosia Fitzmaurice from Queen Mary University of London. "It's not anthropocentric anymore but it's general and positioning human beings as part of nature, I think."

In principle, this shift allows lawyers to defend places and entities in the natural world using legal mechanisms that may previously have been applicable only to human beings. There is a problem, however. Lawsuits are not speedy things. Nor are they cheap.

Pentinat argues that environmental litigation nonetheless has an important role to play by pressuring those with the power to make significant changes that could slow climate change or cut pollution. "At least it's a way to raise awareness and highlight the responsibility of our states," she says.

Environmental litigation can take many forms, however. It can be broad, targeting the big picture climate crisis, or more locally focused. A grassroots attempt to stop a company polluting a particular area, for example.

A GLOBAL CONCERN, A LOCAL ISSUE

If a clean, healthy, safe and sustainable environment really is a human right then clearly it applies right around the world. This is important to think about because not everyone is affected by climate change equally, though we're all affected by it in some way.

ABOVE Vanuatu has experienced an annual sea level rise of 6mm since 1993, almost twice the global average

ABOVE RIGHT Saami reindeer herders must now provide supplementary feeding due to a loss of vegetation

What do people who experience the worst effects of climate change, pollution, or biodiversity loss think about the possibility of asserting their legal right to a cleaner world? These issues are not simple, as pointed out by Näkkäläjärvi, referring to Saami reindeer herders. On the one hand, changes associated with a warming climate are evident. Winters have become warmer, the weather is less stable and changes to vegetation mean that herders are having to supplement reindeer diets. "As a result, traditional knowledge and language changes," says Näkkäläjärvi.

On the other hand, however, some reindeer herders view change and lost traditions as a natural development. Plus, some Saami people may be sceptical that human rights declarations and legislation at national and international levels will really serve them well.

"The question is, will Saami needs be included in these aims and agreements, or do Saami have to adapt once again to meet the needs of the majority?" asks Näkkäläjärvi.

In some cases, legal action may be geared towards establishing what's owed by wealthier, more polluting nations to smaller countries that are the worst affected by climate change. This appears to be a key motive behind Vanuatu's plan to request an advisory opinion on climate change from the International Court of Justice.

The Pacific island nation, which is threatened by sea level rise and extreme weather, seeks to find out what the court has to say about the rights of its citizens to be protected from the effects of climate change in the future.

"EXTREME HEAT IS ALREADY A PROBLEM IN CHAD, WITH TEMPERATURES OFTEN REACHING 50°C DURING THE SUMMER PEAK"

SETTLING ON A SOLUTION

All civil legal action is, ultimately, about achieving a satisfactory decision or resolution to a problem. But it's not always obvious that a lawsuit is the best way to do this.

In New Delhi, one of the most polluted cities in the world, opinions are divided as to how to clean up the air.

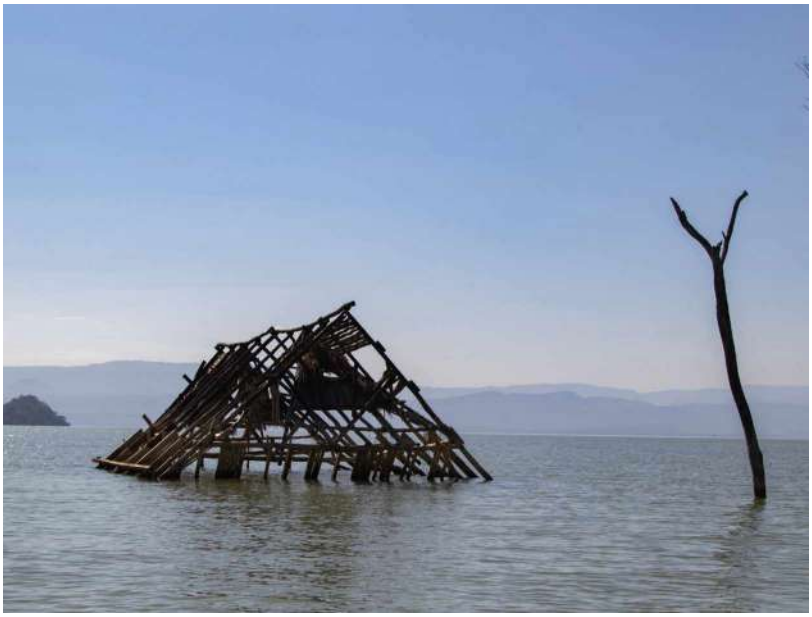
The choking smog is worst in the winter months, from around October till February, explains Khare. Vehicle pollution, dust from digging and construction work as well as the smoke emitted by fires burnt for warmth, or those lit to clear agricultural areas outside the city, all contribute to the problem.

"We should have clean air," says Khare. He's unsure, however, of how much public support there would be for claiming the right to clean air in the context of a legal case.

Others point out that there are many people involved in polluting industries or activities such as burning biomass in India who would stand to benefit from cleaner air, but who might also question whether their livelihoods would suffer if they had to change their ways.

And yet, the prospect of raising litigation to address these issues remains. A senior advocate in India's Supreme Court is among those exploring a legal route towards tougher action on the sources of pollution, such as wood fires.

Anshuman Tiwari, a PhD candidate at the London School of Economics, argues that the language of human rights might be helpful when it comes to foregrounding some environmental



issues, but perhaps not all. In India, he suggests the focus should instead be on providing incentives to move away from polluting activities.

"The focus on health impacts is understandable, but what people miss is that all of north India could be growing much faster," he says. Based on research he has yet to publish, he argues that by reducing pollution – perhaps by paying people not to burn materials that contribute to it – the overall economic productivity of the country could rise by a few percentage points. Given India's huge GDP of $2.6tr, that would represent a big divide.

WHO BENEFITS?

The advantage of taking a human rights-based approach to environmental protection, however, is in making sure that efforts to safeguard the natural world are of direct benefit to the people who suffer when it's degraded, says Hindou Ibrahim, an environmental activist and geographer from Chad. That's in contrast to a system in which a company or government is able to 'offset' harmful activities by paying a carbon tax or supporting tree planting in some other location, after felling a patch of rainforest, for instance.

Her point is that this often doesn't directly benefit the people who used to live in the forest or who relied on its living ecosystem for food, medicine or shelter.

Ibrahim notes how extreme heat is already a problem in her home country of Chad, with temperatures often reaching 50°C during the summer peak. Were the world to reach 2°C or 3°C of warming above pre-industrial levels, temperatures would soar even higher. "It's going to be unliveable," she says, pointing out why a significant reduction in global emissions would be so meaningful for people at the frontline of climate change.

"All the talk about climate change must be [from a] human-rights-based approach," she adds.

Nakalembe stresses how floods and landslides have become increasingly severe in countries such as Kenya and Uganda, making the lives of many people miserable. She has studied such impacts first-hand. Often, those affected by such disasters express deep frustration at having worked hard to establish a certain livelihood only to watch it – literally – get washed away a few years later, she says.

"It just seems like they don't have a choice, they have to keep working in the field and hope that things will be okay," she explains.

In principle, human-rights-based legal action could help to redress this situation. And it could bring pressure to bear on many other issues – from access to clean air to the protection of glaciers. The difficulty, perhaps, is making governments and industry truly accountable for these things via such action, notes Nakalembe.

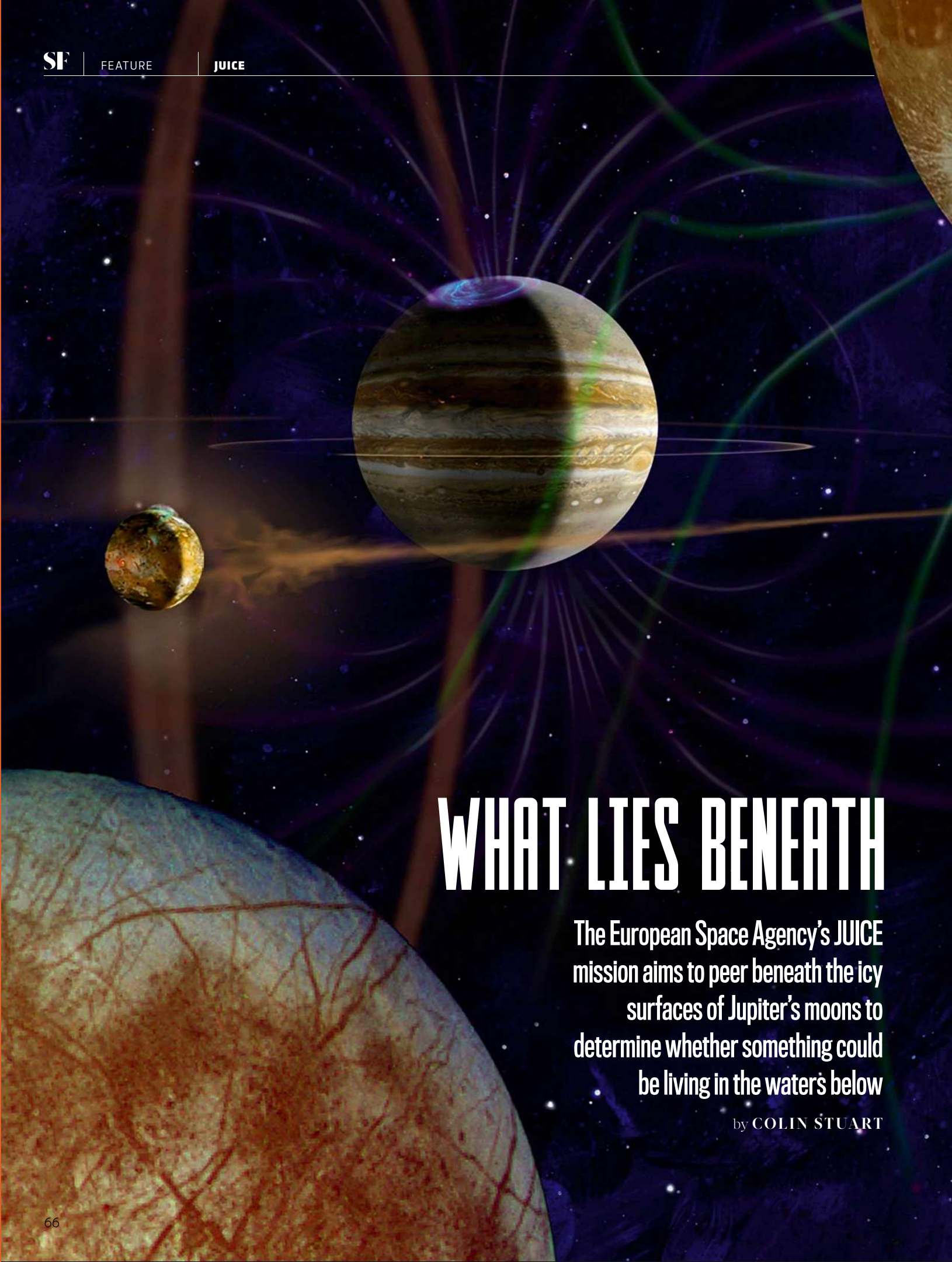
But she adds that when people are informed that they do have a human right to a clean environment, and that there are mechanisms through which they can assert that right, then the possibility of doing something powerful emerges.

In 2022 and beyond, you can expect more lawsuits in this vein to spring up in local, national and international courts of law. Will that lead directly to solutions that solve the climate crisis and clean up the world's pollutants? We'll see. For now, the jury is still out. **SF**

ABOVE Flooding in the Ritt Valley in East Africa has worsened due to climate change, leading to thousands of people losing their homes and jobs

by **CHRIS BARANIUK** *(@chrisbaraniuk)*
Chris is a freelance science journalist based in Northern Ireland, focusing on nature, medicine and technology. He has appeared on BBC World TV, BBC World Service Radio, BBC Radio 4, Sky TV and other international channels.

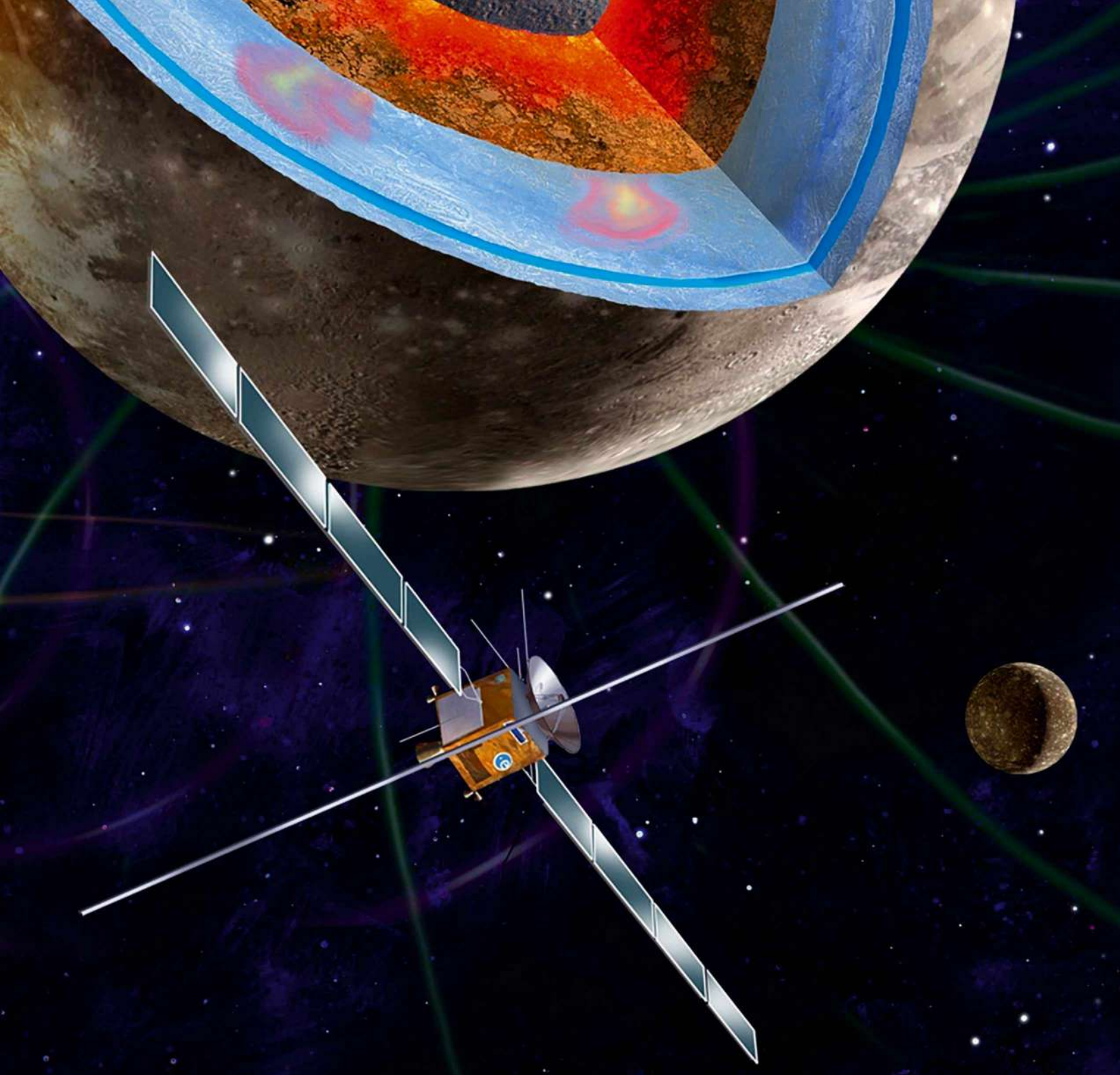
GETTY IMAGES X3



WHAT LIES BENEATH

The European Space Agency's JUICE mission aims to peer beneath the icy surfaces of Jupiter's moons to determine whether something could be living in the waters below

by COLIN STUART

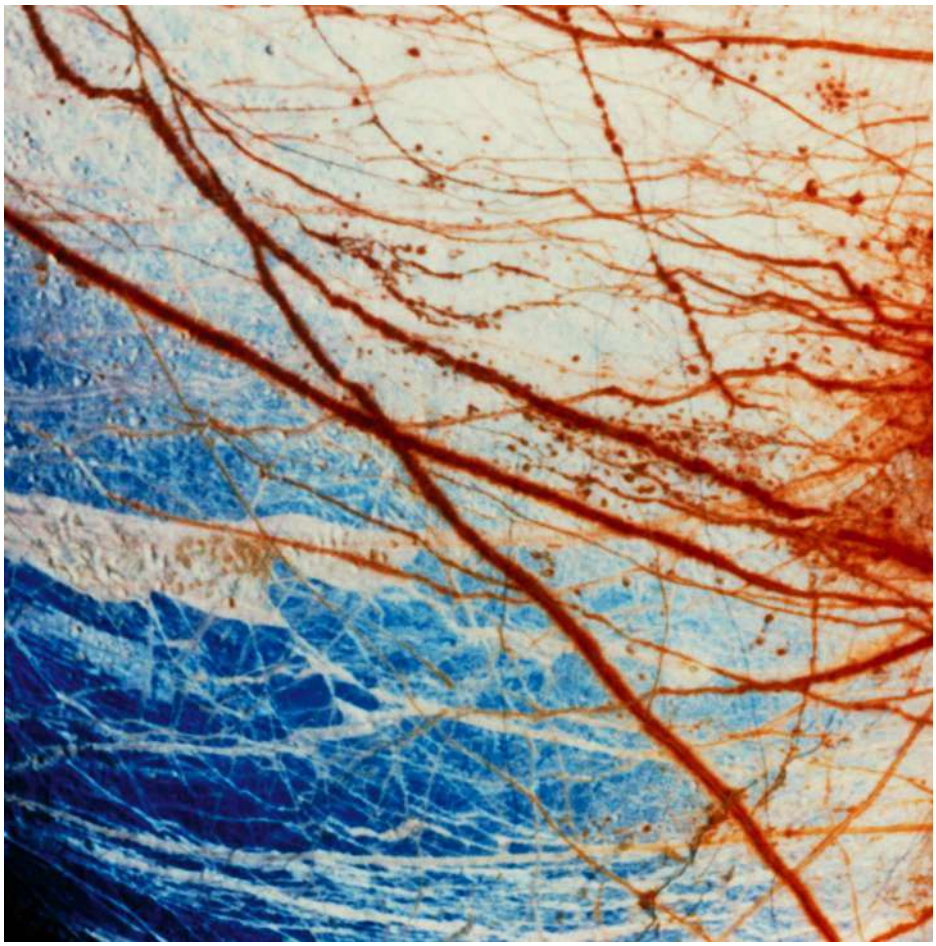


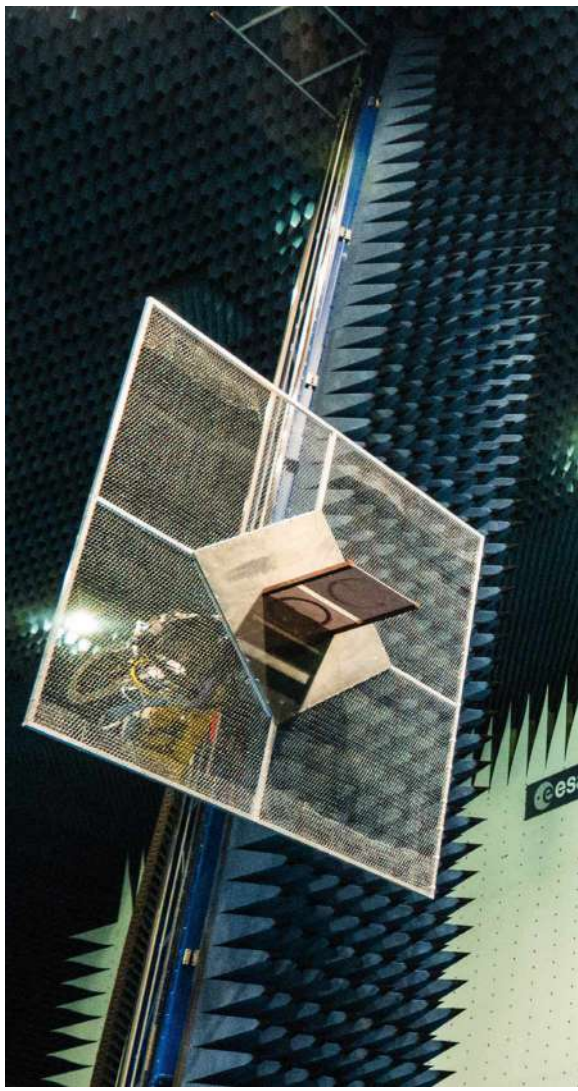
ESA

Deep beneath the salty ocean, the sea floor is cracked. Hot gases from the layers below bubble into the water, sustaining colonies of microbial life that are eking out an existence far from the sunkissed surface.

This may sound like a scene from the bottom of Earth's vast oceans, but it's actually a possible description of Europa – one of the icy moons orbiting Jupiter. And thanks to the upcoming Jupiter Icy Moons Explorer (JUICE) mission, we may finally have the opportunity to find out how accurate that description is.

Astrobiologists – scientists who look for signs of life beyond the confines of our planet – have long adhered to a simple mantra: follow the water. That's because every living thing on Earth, from the tiniest bacterium to the mighty blue whale, needs liquid water to survive. While alien life without water may be possible, looking for that molecular marriage between hydrogen and oxygen is an excellent place to start.





ABOVE Scores and fractures criss-cross Europa's icy crust. The red-brown material is thought to be salt and sulphur compounds that have been modified by radiation

In the hunt for H_2O, much has been made of the habitable zone – the narrow ring around a star where the temperature is just right for liquid water. Earth sits in this region, so the majority of our water neither freezes nor boils. But the habitable zone is an imperfect concept. "At least five objects in the outer Solar System have sub-surface oceans," says Dr Mark Fox-Powell, an astrobiologist at the Open University. All are far beyond the outer reaches of the traditional habitable zone. Three of these oceans can be found beneath the surfaces on a trio of Jupiter's moons: Europa, Ganymede and Callisto. Jupiter has a habitable zone of its own. The required heat isn't coming from the Sun, but from the gravity of Jupiter. It expands and contracts the moons, warming them up like squash balls.

While we have been to the Jovian system many times, these moons have rarely been the main attraction. "The last time we were there studying them directly was with the Galileo spacecraft in the 1990s," says Fox-Powell. Instead the focus has tended to fall on the giant planet itself. But now there's JUICE, a dedicated mission heading for its icy satellites.

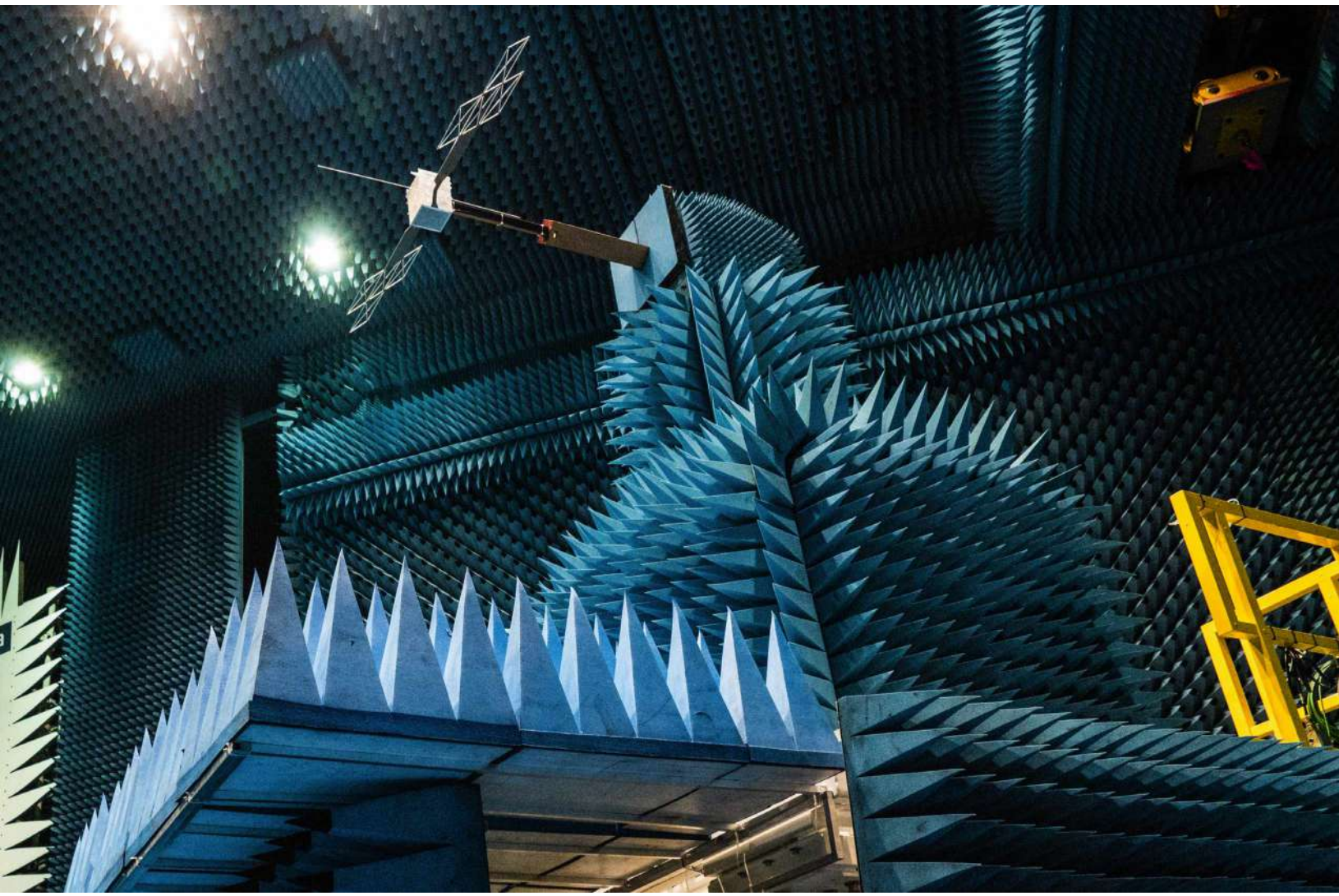
BEST-LAID PLANS

At the heart of the JUICE mission is a spacecraft that's been built by the European Space Agency (ESA). It bears a slight resemblance to a giant bird, with solar panel wings stretching out on either side of spacecraft's main body. The sunlight at Jupiter is 30 times dimmer than the light that reaches Earth, so the panels need to be big. They cover an area equal to $85m^2$, or about half the size of a volleyball court. Its three-metre-diameter antenna will send the data JUICE collects back to mission control, although it will take almost two hours to travel more than the half a billion kilometres to Earth.

ESA had been working towards launching JUICE in 2022, until the coronavirus pandemic hit. Instead of the planned lift off, the coming year will now see frantic activity as ESA scrambles to claw back the time lost during lockdown and make the final preparations needed to ready the landmark mission for its rescheduled launch in 2023.

The original plan was for JUICE to take a convoluted route, involving five flybys of Earth, Venus and Mars to use the planets' gravitational might to slingshot the spacecraft towards Jupiter,

SCIENCE PHOTO LIBRARY, ESA/MCOWAN



ABOVE A scale model of the RIME antenna undergoes testing at the Hertz facility in the Netherlands

a journey that was set to take 7.5 years. ESA has yet to reveal exact details of the new timeline, but JUICE should arrive at Jupiter at the start of the 2030s. Once there, it will spend at least three years exploring Europa, Ganymede and Callisto. It will be joined by NASA's Europa Clipper mission, currently scheduled for launch in 2024 and arrival in April 2030.

WATER, WATER EVERYWHERE

"WHILE WE HAVE BEEN TO THE JOVIAN SYSTEM MANY TIMES, THE MOONS HAVE RARELY BEEN THE MAIN ATTRACTION"

We've known about these moons for a long time. Along with Io – the most volcanically active place in the Solar System – Europa, Ganymede and Callisto make up the so-called 'Galilean moons', first seen by the Italian astronomer Galileo at the start of the 17th Century. Of the trio that JUICE will focus on, Europa tends to steal the limelight. "It's definitely the poster child of the Galilean moons," says Fox-Powell. That's because beneath its icy crust sits an ocean that contains more liquid water than all of Earth's seas, lakes and rivers combined. If there's life swimming around in our oceans, could the same be true of Europa?

Part of the problem is that the ocean is hiding beneath a thick, icy surface. "We can't access it directly," says Fox-Powell. Thankfully, scientists think the icy crust and the water are interacting, a bit like the molten rock beneath Earth's surface that breaks through during volcanic activity. "It means we can use material on the surface to study the oceans indirectly," Fox-Powell says.

We may even be able to collect a sample of that material, despite JUICE being unable to land on Europa. The spacecraft is carrying 10 high-precision instruments to Jupiter, including the Particle Environment Package (PEP). "It's designed to study dust and other molecules that have been kicked up from the surface," says Fox-Powell. "It's not impossible that, if that material came from the oceans, it could contain molecules that are indicative of life."

If there are organisms in Europa's oceans, then they'll need a source of energy. Hidden beneath the icy crust, they can't get that energy from the Sun. Fox-Powell sees two potential options. The Jovian system is an environment flooded with intense

levels of radiation as Jupiter's magnetic field slings and funnels high-energy particles around. "Any ocean material that ends up on the surface is going to be irradiated," Fox-Powell says. That changes the chemistry of the ice. One likely scenario is that the radiation is breaking water into hydrogen and oxygen, with that oxygen potentially seeping back down into the ocean below. Other potential by-products include compounds containing the element sulphur. "On Earth they're known to support microbial life," says Fox-Powell. JUICE will help us to learn more about that ocean-surface boundary and to what extent the conditions are suitable for biology.

Alternatively, life may have colonised the ocean floor. On Earth there are whole communities of organisms that thrive on the seabed without any sunlight whatsoever. The source of their energy is hydrothermal vents – cracks in the boundary between the ocean and Earth's hot interior. JUICE could help us see how geologically active Europa's interior is.

AN ASTRONOMICAL RELIC

While Europa grabs the lion's share of public attention, it's not JUICE's main target. The mission will only flyby Europa twice, but will buzz past Callisto on 12 occasions. Callisto is the outermost of the four Galilean moons, so is least affected by Jupiter's gravity and radiation. In contrast to Europa, whose surface is constantly reshaped by material welling up from beneath the ice, Callisto has the oldest surface in the Solar System. Unchanged for billions of years, it's pockmarked by more impact craters than any other body orbiting the Sun.

Astronomers suspect that a 200km-deep ocean lies beneath Callisto's ancient surface. This is where JUICE's Radar for Icy Moons Exploration (RIME) instrument will come into its own. It will transmit radio waves that can penetrate the icy shells of the Galilean moons down to a depth of around nine kilometres. From the way the radio waves are reflected back, we should be able to learn more about the moons' internal structures. Another approach will be provided by the Gravity and Geophysics of Jupiter and Galilean Moons (3GM) instrument. It will measure the gravitational fields of Callisto and the other icy moons, which will reveal how different layers of material – including water – are stacked up inside them.

"IT WILL BE THE FIRST TIME THAT A SPACECRAFT FROM EARTH HAS ORBITED A MOON OTHER THAN OUR OWN"

JUICE will also use Callisto for a leg-up. Mission controllers will use the gravity of the moon to increase the spacecraft's inclination by about 30° so it can get a better look at Jupiter's polar regions – the source of Jupiter's vast and intense magnetic field.

MAGNETIC ATTRACTION

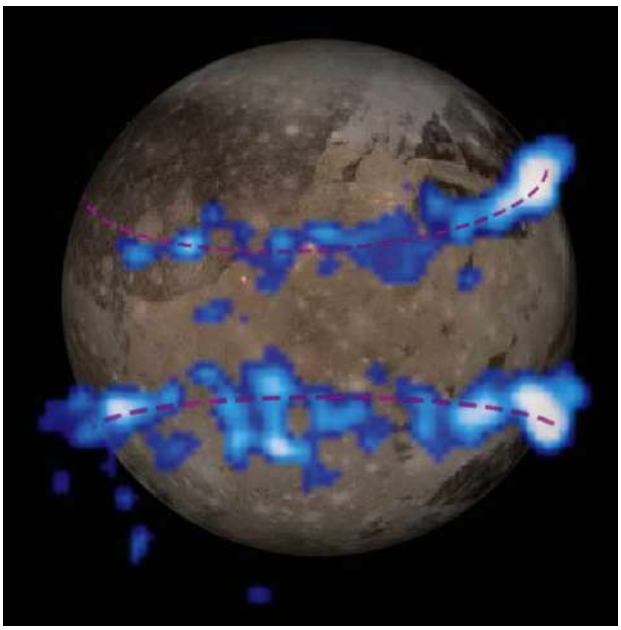
It is magnetism that determined where JUICE will spend the bulk of its time: Ganymede. Along with a dozen fly-bys, the spacecraft will also go into orbit around Ganymede and stay there for eight months. It will be the first time that a spacecraft from Earth has orbited a moon other than our own.

"Ganymede is the most exciting body in the Solar System," says Prof Michele Dougherty, from Imperial College London. For one thing, it's bigger than any other moon. In fact, it's bigger than the dwarf planet Pluto and the planet Mercury. Like Europa, it's also thought to have a sub-surface ocean that contains more water than we have on Earth.

Yet it's Ganymede's magnetism that's the main attraction. It's unique among the moons of the Solar System for having a magnetic field of its own. Dougherty is the principal investigator for J-MAG – an instrument on JUICE for measuring magnetic fields. J-MAG is located at the end of a 10.6m-long boom to keep it away from magnetic interference from the main spacecraft. Its sensitive electronics are locked inside a lead-lined vault to protect them from Jupiter's intense radiation.

Dougherty wants to measure Ganymede's magnetic field in detail, including how it interacts with Jupiter's own magnetic field. Astronomers using the Hubble Space Telescope have spotted

SCIENCE PHOTO LIBRARY, NASA/ESA, AIRBUS/ROLF SCHWARK



ABOVE Plumes of water from the ocean below often erupt through Europa's icy surface, as illustrated here

ABOVE RIGHT Auroral activity on Ganymede holds clues as to the magnetic influence of Jupiter

LEFT A simplified mock-up of the JUICE spacecraft is used to carry out tests

auroral activity on Ganymede. The equivalent of the northern and southern lights on Earth, the auroras should wobble around Ganymede's poles due to the influence of Jupiter's magnetism. That they don't suggests a sub-surface ocean of salty water on Ganymede that's conducting electricity and counter-balancing Jupiter's magnetic might. Studying Ganymede's magnetic field could provide further clues about the size and nature of this ocean. In turn, that could help us understand if it's a place that may be home to alien life.

Separating Ganymede's magnetic field from Jupiter's is far from straightforward, though, particularly given how much the planet dominates its surrounding satellites. "It's like trying to find needles in a haystack," Dougherty says, "but they're changing size, shape and colour all the time." Still, she's confident the team can pull it off. The flybys will be used to practise, with the really important data coming once JUICE settles into orbit around Ganymede. "The results are going to be spectacular," Dougherty says.

MOONS HAVE POTENTIAL

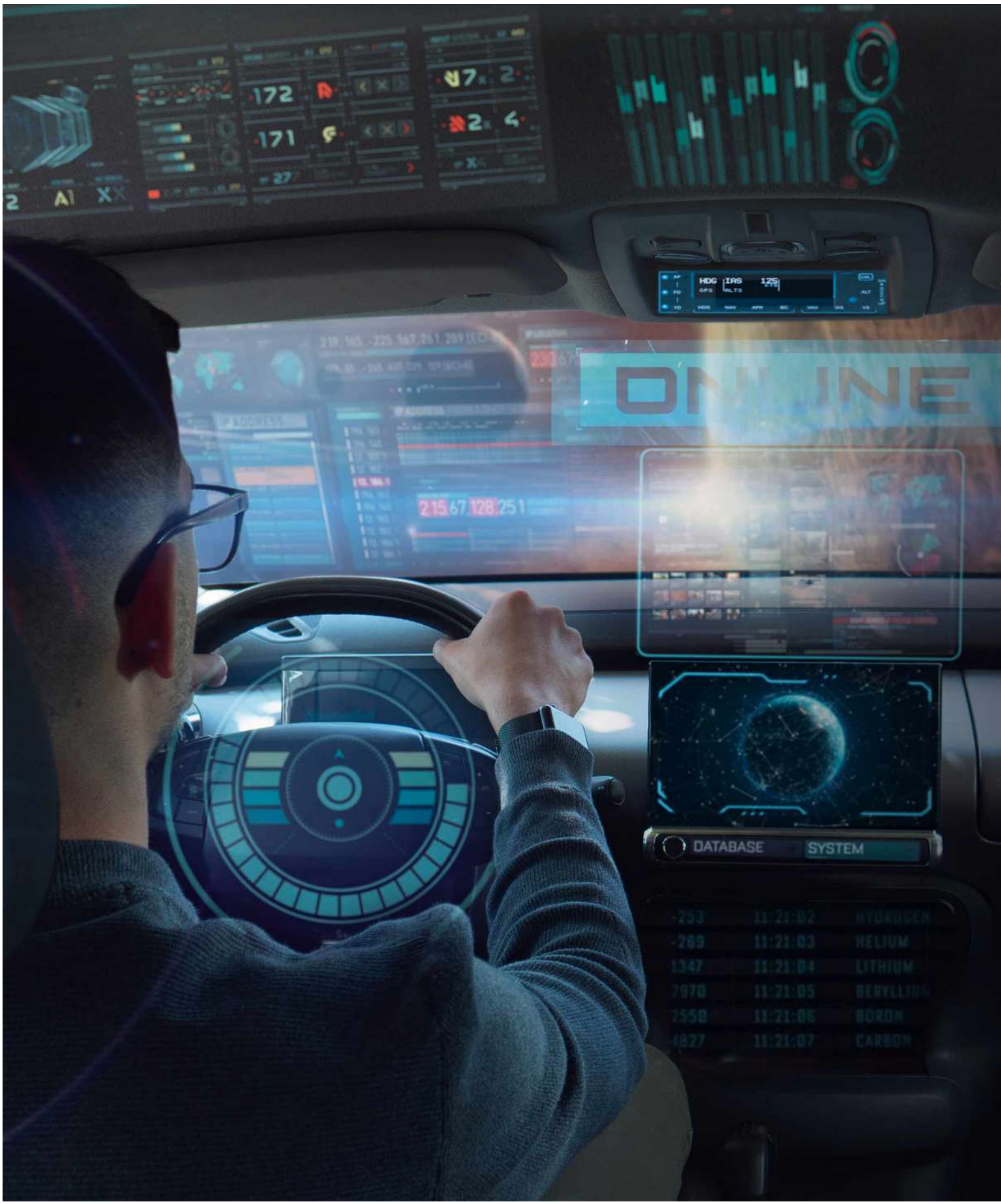
If she's right, it'll be the crowning achievement at the end of a long and winding road. Dougherty was previously involved in another flagship spacecraft: the Cassini mission to Saturn. Discussions about JUICE began in earnest in 2008, when Cassini had already been at Saturn for four years. It was one of Saturn's moons – Enceladus – that made people sit up and take notice. "My team was instrumental in discovering that Enceladus has plumes of water vapour," Dougherty says. Water from a sub-surface ocean was being spat out into space, showing that it's possible to find water beyond the traditional habitable zone.

"The discoveries at Enceladus showed us that focusing on moons of the outer planets was a good thing to do." Soon a plan was hatched to get a closer view of Jupiter's icy moons. Not that it's all been plain-sailing. At one point during the pandemic, with labs closed, Dougherty's team was building parts of J-MAG on their kitchen tables. "Building an instrument is always stressful, but the pandemic took that stress to the next level," she says.

That effort is all the more remarkable given that the team will eventually destroy all of that hard work. Sometime in 2034 the spacecraft is likely to run out of propellant. Without any fuel, scientists will no longer be able to manoeuvre it around the Jovian system. So the team will do what's been done before with spacecraft like Cassini and the MESSENGER mission to Mercury: deliberately crash it.

By smacking into the surface of Ganymede, JUICE will provide one final experiment to see what this gargantuan moon is made of. Its days of exploring Jupiter's icy moons will be over, but scientists will continue to pore over JUICE's collection of valuable data for a long time afterwards. "In 20 years' time, our understanding of these moons will be different," says Fox-Powell. "JUICE is going to provide a real revolution." It could, finally, tell us whether or not we're alone in this vast and often surprising Solar System. **SF**

by **COLIN STUART** *(@skyponderer)*
Colin is an astronomy author and speaker. Get a free ebook at ***colinstuart.net/ebook***


DATABASE
SYSTEM

AUGMENTED INTELLIGENCE: A BETTER TYPE OF AI?

Why are we working so hard to make computers that compute better, when we could be using computers to help us think and act better?

by **DR PETER J BENTLEY**

For years, writers, scientists and entrepreneurs have shown us visions of our future relationships with computers and robots. These vary from the devastation of autonomous robots annihilating us, to the marvels of superhuman enhancement in robot suits. While the *Terminator* and *Iron Man* concepts push those ideas to the extreme, they highlight a clear choice in our use of technology. Should we aim for total automation with the target of greater safety and higher efficiency? Or should we aspire to augmentation – using technology to enhance our abilities without replacing us? As artificial intelligence and robotics mature enough to become integrated into everyday life, we need to start making this choice. We need to choose wisely, or we might just automate ourselves and the natural world out of existence.

GETTY IMAGES

ABOVE
The textiles industry was one of the first to see machines taking the place of people on the production lines

> "Much of the Industrial Revolution was premised on the idea that automation is better"

Humans have always been fascinated by automation. Centuries ago, mechanical creations called automatons were constructed to mimic musicians playing, birds singing, or animals moving. Much of the Industrial Revolution was premised on the idea that automation is better: fabrics could be woven faster and cheaper. Never mind the pollution or the awful working conditions – the products are so much more affordable!

The idea continues in our factories today, where everything that can be automated is automated. Car factories are the largest adopters of robots, and today all welding and painting is done by robots, with ambitions for entire vehicles to soon be built automatically. And while robots have been around for several decades, the last 10 years have seen an explosion in artificial intelligence (and specifically methods such as machine learning). These advanced computer algorithms inspired by the way the brain works provide the latest way we can perform automation.

AUTOMATICALLY BETTER

We can use artificial intelligence to drive our vehicles, to design products, even to compose music or make art. Artificial intelligence will soon be able to imitate our images and sounds perfectly, meaning that actors and performers can be computer-generated. Artificial intelligence can generate text in any style and content, so writing can be automated. It can understand our patterns of behaviour and influence us automatically – enabling the marketeers' dream of encouraging us to purchase or vote in ways we otherwise might not.

While automation is a commonly touted goal by those developing such technologies, it takes a certain genius to imagine something better. Instead of an artificial intelligence, the idea of augmenting our own intelligence with technology was first proposed in 1960 by an American psychologist and computer scientist called Joseph Carl Robnett Licklider, in an important article titled 'Man-computer symbiosis'. Licklider went on to help create the modern computing world as we know it, from the ARPANET (which later became the internet) to graphical user interfaces. His ideas were revolutionary, for he believed that the new computer technology should be used for 'intelligence amplification' – not automation.

His influence was vast and as computer technologies grew more advanced, most software was created to amplify our abilities. A word processor helps us write better, it doesn't write for us. A computer-aided design (CAD) package helps us design, it doesn't create designs for us. Likewise in our vehicles, technologies now exist to help us park, avoid collisions and keep us safe. The whole philosophy of augmented intelligence is to put humans first, and technology second.

And here's where we hit the turning point in history. Those who favour automation are increasingly squeezing the augmented intelligence solutions out. We've now got the technology to do it, so why not? If my word processor can check spelling and grammar, why not let it reword the whole sentence? Or write the entire piece? If my

GETTY IMAGES, ALAMY

car can avoid a collision, why not let it drive? If my art package can blur the background of an image, why not let it create a new background? Or a new image? If my medical software can suggest drugs, why not let it diagnose and treat me? Those who favour automation always use the same arguments: it's cheaper, more efficient, faster and better. But do these arguments always hold water?

TECH SUPPORT

When we fully automate systems, we put technology first and humans second. A fully automated factory is designed to make the robots work optimally, not necessarily to be safe or comfortable for human workers.

In the early days of Tesla, worker injuries were common. Elon Musk's solution? Automate further and remove the humans. "You really can't have people in the production line itself. Otherwise you'll automatically drop to people speed," Musk told his investors in 2016. "There's still a lot of people at the factory, but what they're doing is maintaining the machines, upgrading them, dealing with anomalies. But in the production process itself there essentially would be no people."

It's a classic geek dream, but it ignores the fact that customers are increasingly looking for customised options on their vehicles, making their manufacture increasingly difficult to automate. People are the most flexible and adaptive part of any factory, so instead of trying to replace them with difficult-to-program and complex robots, perhaps it would make more sense to enhance the capabilities of experienced workers with robotic tools that they can control, combining the speed and efficiency of robots with the adaptability of people. The latest exoskeleton robotic suits from ULS Robotics provide exactly this solution – Ford and Hyundai are trialling such suits at the moment.

Research is also casting doubt on the idea of fully autonomous vehicles. Turn your car into a robot and you have to make the roads fit the cars first, and people second. Autonomous cars won't understand pedestrians. They won't have that human connection between the driver and someone crossing the street, the subtle body language that says, "I'm crossing now" and "I've seen you, go ahead." They won't understand the strange contortions and undulations of Asian or European country roads under (increasingly) extreme weather conditions, or the changing fashions and products that make driving such a varied experience. So we must regularise ➤

BELOW Robots take care of a lot of the car construction at BMW's plant in Oxford, which builds Minis

ABOVE An engineer at Hyundai sits on a 'chairless exoskeleton' while fixing one of the company's wearable medical exoskeletons

all roads to make them fit the cars, spending a fortune on upgrading infrastructure. We must standardise all interactions between people and vehicles. We must change our environment to fit the needs of our robots, putting the robots first and the people second.

There are even warnings that autonomous vehicles may not reduce traffic. A recent study suggested that personally owned autonomous vehicles can result in more traffic as the empty cars shuttle to pick up their owners (or even pick up packages from stores), and one way to avoid parking charges is to tell your vehicle to keep driving around. Car-pooling may be a solution to these problems – but in the age of global pandemics, it's unlikely to be a popular solution.

Autonomous vehicles even have problems when we're behind the wheel – research shows we struggle to transition from autonomous modes to manual, and our driving skills will only deteriorate as we drive less, making us more dangerous on the roads.

But everything changes if we put people first. Instead of aiming for fully autonomous vehicles, why not aim for superhuman drivers? Technology that makes drivers better, safer, more aware and makes the task of driving more engaging? The same artificial intelligence tech used in autonomous vehicles can be used to achieve this, providing drivers with more multisensory feedback. See the accident two miles away on a heads-up windscreen display long before your eyes could. Be alerted to invisible black ice on the road. See the cyclist dressed in black on a dark country road with no lights. Be warned by tactile feedback on the accelerator that there's a collision risk to give you time to respond, rather than have a frightening last-second automatic braking system. No more blind spots, as your car will be able to see all around itself and show you exactly what's going on. No more falling asleep or drunk driving as the car can keep an eye on you and ensure you're fit to drive. New augmented-reality technology is becoming available to make windscreen displays feasible, and this use of artificial intelligence is a lot safer and more reliable than attempting to have it drive cars. Why shouldn't our technology make us better at driving, rather than worse?

"Instead of aiming for autonomous vehicles, why not aim for technology that makes drivers better, safer and more aware?"

SPECIAL EFFECTS

Artificial intelligence can, in theory, enable us to replace all actors, singers, musicians and composers. But while this might be cheaper than paying their salaries, it's putting the technology before the people. Wouldn't it be better to ensure that all our art is created by artists, but that those artists have high-tech tools to help them create their works?

GETTY IMAGES, THIRD SPACE LEARNING

LEFT
Third Space Learning uses artificial intelligence to monitor pupils' engagement so the teacher can adjust the lesson according to how it's going

Don't automate the painting; provide the artist with a new kind of medium to work with. Don't replace the actor or disguise her skill through post-production; give her the ability to fine-tune her image as she performs, digitally altering her appearance and sound to suit her performance.

Artificial intelligence can already design for us automatically. It can do everything from creating radical new architecture from scratch, to optimising angles on wind turbine blades. But CAD company Autodesk has no intention of taking choice away from its designers. According to Tonya Custis, the director of artificial intelligence research at Autodesk, "Autodesk's mission is to amplify designers' creativity by using artificial intelligence to assist them with the tedious, routine and constraint-based aspects of their work so they have more time to focus on the art of designing." For example, generative design solutions created by artificial intelligence are suggested as ideas for designers to examine and modify, and artificial intelligence modelling tools show designers exactly how the designs will behave, giving designers greater power, creativity and precision.

The misuse of some artificial intelligence methods has already caused major problems. Automated news curation has been designed to feed us more of the things we like, and sometimes prioritises messages that are more likely to cause upset, such as Facebook's automatic policy that prioritises messages that provoked bigger reactions. These automated learning systems result in our societies polarising around certain views, leading to radicalisation and distortions in the democratic process.

There are similar problems when automated systems are used to make judgements classifying faces, with discrimination being embedded within the software. Again, this is technology first, people second. Decisions that may *affect* people should be made *by* people. Why would we delegate our choices to machines? Isn't this removing one of our fundamental freedoms?

The use of augmented intelligence enables people to make these decisions in a safer and more informed manner. Instead of automated news curation, artificial intelligence can be used to present us with a balanced choice of different topics and opinions. Feeding a child nothing but sweets and ice cream makes for an unhealthy child; give them a varied selection to form a balanced diet and they become healthy and strong. Similarly, if we use artificial intelligence to help provide varied and balanced online media content, then the minds and education of populations become healthy and strong. And instead of using artificial intelligence to manipulate the minds of voters, use it to provide coherent summaries of what voters are demanding to politicians and enable our elected representatives to represent their constituencies more effectively. This is how artificial intelligence can make us better.

Artificial intelligence is also used to feed addictive habits in gaming. Computer games (like much of social media) are designed to hold your attention for as long as possible, by any means necessary. It's resulted in a new epidemic of unhealthy children and adults. In China, a new law is attempting to tackle this 'spiritual opium' by limiting gaming to three hours a week for people under the age of 18.

But the same technologies can be used for good, as shown by the use of artificial intelligence in education. Using the techniques in games that encourage players to keep playing, Third Space Learning aims to monitor student reactions in real-time and provide hints to the educator so that they can adjust their pace and style to suit the needs of their class. A leading panel of artificial intelligence experts at Stanford believes this is the future of teaching: "Over the next 15 years … the use of intelligent tutors and other artificial intelligence technologies to assist teachers in the classroom and in the home is likely to expand significantly."

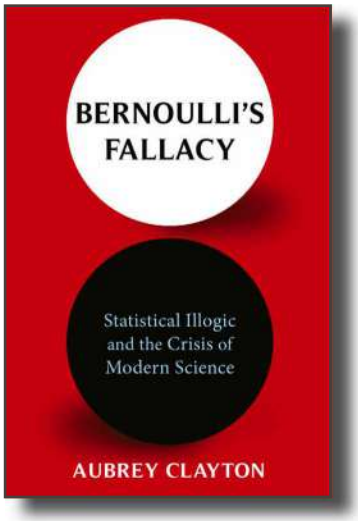
TECH NEUTRALITY

So how do we change things? The first point is to recognise that artificial intelligence and robots aren't evil or inherently bad technologies, any more than were the machines of the Industrial Revolution. When misused for poorly conceived automation, often in the name of efficiency improvements, profitability, or even safety, they cause great harm. But when applied for the good of people, these new, advanced technologies have the power to make us better than we have ever been.

Dumb automation is for the short-sighted. Augment your intelligence – use tech to make you better at what you do. The trick is to be aware that what you use will change you. So use solutions that put people first, solutions that enable you to make your own, more informed, decisions. Don't be a victim of bad tech. Choose technologies that make you a superhuman. **SF**

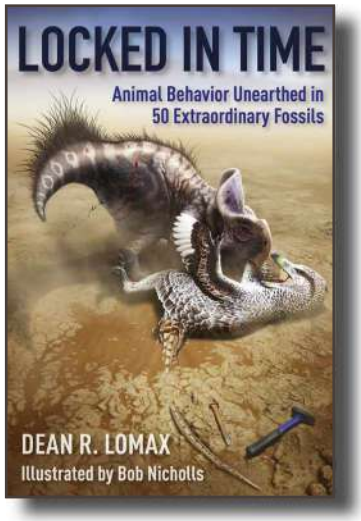
by **DR PETER J BENTLEY** *(@peterjbentley)*
Peter is an honorary professor and teaching fellow at the Department of Computer Science, University College London, and the author of 10 Short Lessons In Artificial Intelligence And Robotics *(£9.99, Michael O'Mara).*

NEW SCIENCE TITLES FROM COLUMBIA UNIVERSITY PRESS



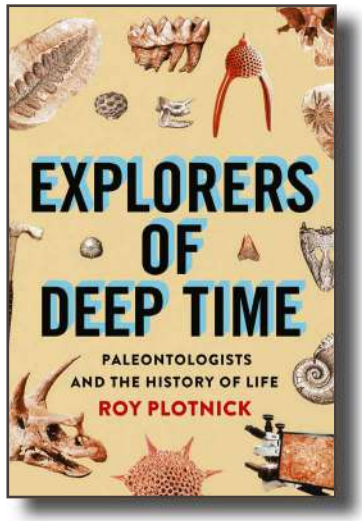
"Anything that gets people thinking about the uses and abuses of statistics is important and Clayton's book does just this."

—Persi Diaconis, Stanford University



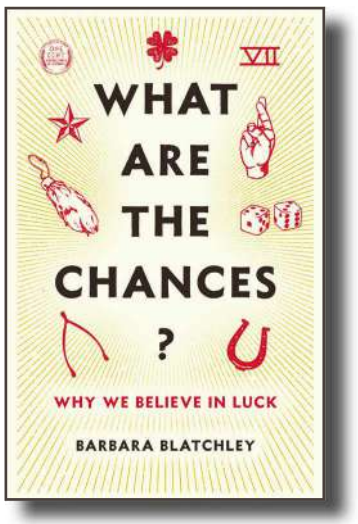
"A rousing romp through the fossil record. Dean R. Lomax's storytelling and Bob Nicholls's artwork reanimate the lifestyles and behaviors of long-extinct species. Revel along as old bones, teeth, and footprints tell the tale of dinosaur mating dances, fighting mammoths, and pterodactyl nurseries."

—Steve Brusatte, *New York Times* best-selling author of *The Rise and Fall of the Dinosaurs*



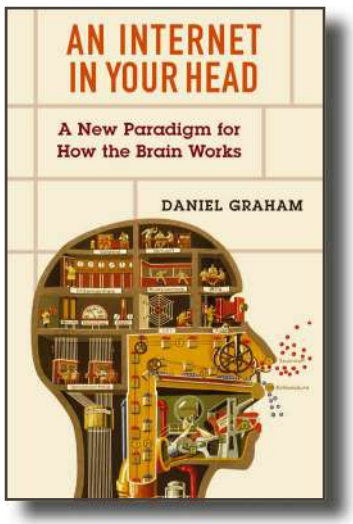
"Plotnick has gone above and beyond to highlight as many of paleontology's contributors as possible, demonstrating that it is an increasingly inclusive, diverse field of study. [The book] is an invaluable tool for the budding scientist and a beautiful homage to the breadth and depth of this discipline."

—Emily Graslie,
host of *Prehistoric Road Trip* on PBS



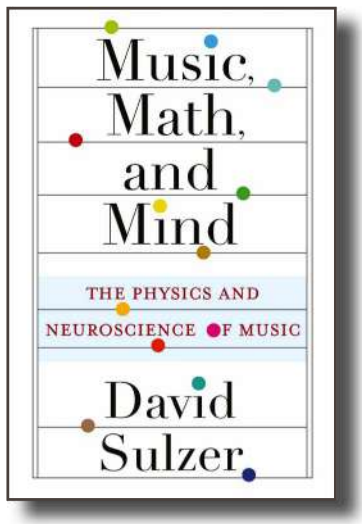
"Barbara Blatchley provides a colorful and accessible look at the fascinating nature of luck. Focusing on the human side as well as the neuroscientific and psychological aspects, she explores what luck is and the role luck plays in our lives."

—David Hand, Imperial College London,
author of *The Improbability Principle*



"A fresh, insightful, and informative perspective on brain function, proposing that communication between neurons resembles signal passing in the internet as a novel metaphor to investigate the brain. [Graham] provides erudite discussions and presents compelling arguments in a lively and clear manner."

—Gabriel Kreiman, Harvard Medical School



"Here is the place to find out about the way crickets make music, and the McGurk effect! The science comes along gently, never intimidating. Only a neurobiologist who is a master composer and musician could have written this wonderful book!"

—Roald Hoffmann,
author and recipient of the Nobel Prize in Chemistry

cup.columbia.edu

Q&A

YOUR QUESTIONS ANSWERED

... HOW DOES A PHONE 'READ' MY FINGERPRINT?
... WHY DOESN'T HALLOUMI MELT?
... COULD YOU PROTECT ASTRONAUTS FROM COSMIC RADIATION BY CREATING A MAGNETIC FIELD AROUND THEIR SPACESHIP?
... WHICH IS BETTER: OPTIMISM OR PESSIMISM?
... HOW DOES A GROUND SOURCE HEAT PUMP BOILER WORK?
... WOULD EARTH BE DIFFERENT IF IT SPUN THE OTHER WAY?
... WHY DO I HAVE SUCH A LOW PAIN THRESHOLD COMPARED TO MY SISTER?
... WHY DON'T HUMANS HAVE A BACULUM?
... WHY CAN CHEMOTHERAPY CAUSE YOUR HAIR TO GROW BACK DIFFERENTLY?

Email your questions to

questions@sciencefocus.com

or submit on Twitter

@sciencefocus

OUR EXPERTS

DR DEAN BURNETT Neuroscientist and author

DR PETER BENTLEY Computer scientist

DR STEVE BRUSATTE Veteran palaeontologist

DR EMMA DAVIES Science writer

PETE LAWRENCE Astronomy expert

DR ALASTAIR GUNN Astrophysics lecturer

LUIS VILLAZON Science and technology writer

DR NISH MANEK Medical expert and GP trainee

DR HELEN PILCHER Biologist and science writer

ILLUSTRATION: DANIEL BRIGHT

SARAH STONE, CHIPPING NORTON

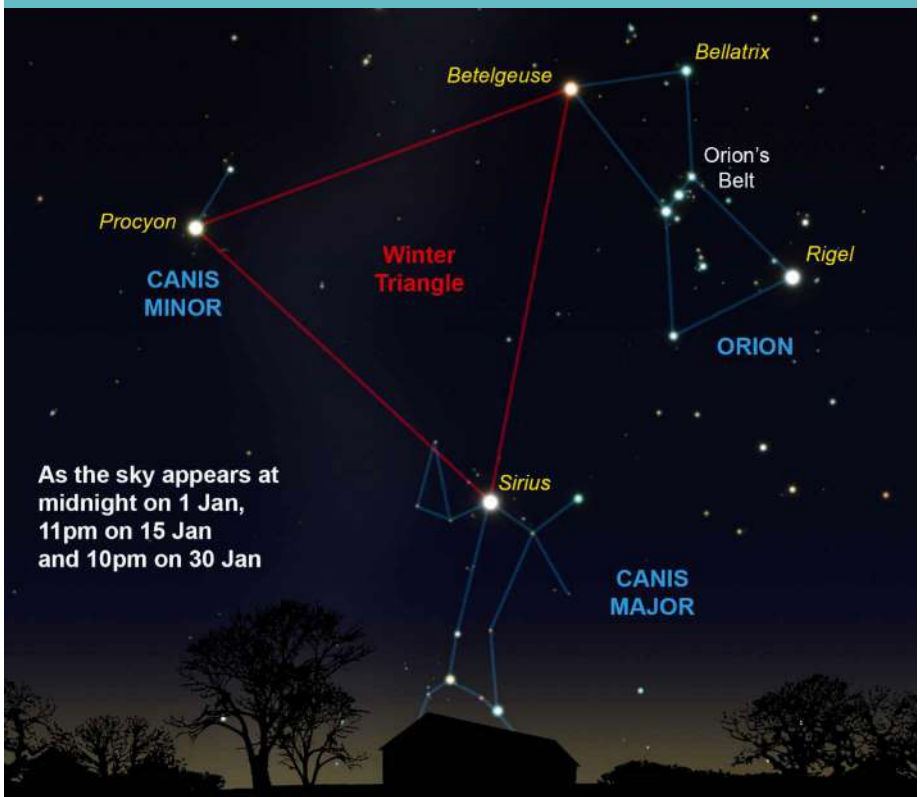
DOES FOSSILISED DINOSAUR POO EXIST?

Dinosaurs, like all animals, would have needed to expel waste. Sometimes pieces of dinosaur faeces turned into fossils, which we can find today. These are called coprolites. Some palaeontologists specialise in studying coprolites and use them to understand what food dinosaurs ate, and how they fit into larger food chains.

The most famous dinosaur coprolite is an enormous specimen found in Late Cretaceous rocks in Canada. At over 30cm long and more than two litres in volume, this huge piece of scat could only have been produced by the largest predator in the ecosystem: *Tyrannosaurus rex*. Although a *T. rex* poo in itself is interesting (or perhaps disgusting, depending on your sensibilities), this fossil is also important. It's full of chunks of bone, which tell us that *T. rex* could bite so hard that it crushed the bones of its prey – a highly unusual way of eating with no obvious modern equivalent.

Other dinosaur coprolites have been found with plants inside, and one even contains decomposing wood – a sign that the dinosaur was supplementing its nutrition with fungi and bugs that feed on ro ing logs. ***SB***

ASTRONOMY FOR BEGINNERS



THE WINTER TRIANGLE

WHEN: DECEMBER TO APRIL

The Winter Triangle is what's known as an asterism, basically an unofficial pattern in the night sky. Asterisms can be of any size, and can be contained within a single constellation or span several constellations (as is the case with the Winter Triangle). The triangle is formed from three bright stars visible in the winter sky; Betelgeuse in Orion the Hunter, Sirius in Canis Major the Great Dog and Procyon in Canis Minor the Little Dog.

Betelgeuse is the red supergiant star that marks the northeast (upper left) corner of Orion's main pattern. Despite being described as 'red', to the naked eye the star appears to be tinted orange. The centre of Orion is marked by three stars of similar brightness sitting in a line, forming another asterism known as Orion's Belt. Follow the line of the belt southeast (down and left) and eventually you'll arrive at Sirius the Dog Star, the brightest night time star.

Sirius appears bright because it's close. At a distance of 8.7 light-years, it's one of the Sun's nearer neighbours. For comparison, Betelgeuse is 548 light-years away. From the UK, Sirius never gets very high in the sky. This causes its light to be affected by low level atmospheric turbulence and it appears to scintillate (the technical term for twinkle) quite noticeably. It'll often ash vivid colours too, an effect caused by atmospheric dispersion – light from low-altitude objects passing through our atmosphere and spreading into a spectrum of colour.

The third vertex in the Winter Triangle is Procyon, the main star in the small constellation of Canis Minor, the Little Dog. Locate Procyon by extending the top of Orion from Bellatrix through Betelgeuse, for 3.5 times. When you arrive at that point, look south and the brightest star seen will be Procyon. Now, to visualise the Winter Triangle just join the dots! ***PL***

HAMISH ANDERSON, SHREWSBURY

HOW DOES A SMARTPHONE 'READ' MY FINGERPRINT?

Phones use one of three different technologies to read your fingerprint: optical, capacitive or ultrasonic. An optical fingerprint reader is the oldest of the three. It uses a specialised miniature camera to take a picture of your finger, often backlit with little LEDs or the phone's screen. Unfortunately, these sensors are easy to fool – even a good photo can trick them, so it may be combined with a capacitive sensor, the second technology, to check there is really a finger there.

A capacitive fingerprint sensor uses a grid of tiny capacitors that store electricity, which is discharged only at the points where your fingerprint ridges touch. An array of thousands of capacitors can then be used to map the pattern of your fingerprint. Sometimes these sensors also support swipes or force sensing.

The third and most advanced form of fingerprint sensing uses ultrasonics. Much like the ultrasonic scanners used for medical purposes, an ultrasonic sound pulse is transmitted to your finger and the reflected pulse is measured. Bats, whales and dolphins use ultrasonic to understand the shape of their surroundings; the sensors on a smartphone use it to understand the 3D shape of the ridges in your fingerprint. It can even work through the phone screen. ***PB***

ANDY MACKINTOSH, DUNDEE

WHY DOESN'T HALLOUMI MELT?

For a cheese to melt it needs a protein structure that stretches in the frying pan or under the grill. Halloumi contains a tightly knit three-dimensional network of milk proteins that hold fast during cooking.

The cheese is made by coagulating milk into lumpy curds, which are scooped out and pressed to remove the remaining liquid. The dry curds come together when they're heated at up to 90°C in purified whey, then the resulting cheese is sprinkled liberally with salt.

The heating step is the secret to halloumi's heat resistance, causing protein networks to retract and strengthen. The heat and salt also kill acid-forming bacteria that could weaken the cheese's structure. Halloumi is therefore less acidic than melting cheeses. ***ED***

JONATHAN NEVILLE, LUTON

HOW DOES FREEZE DRYING WORK?

It's actually pretty similar to regular drying. Molecules in a liquid are more tightly bound than in a gas, but at the surface there are always some that get bumped enough by their neighbours to jump clear – like a snooker ball getting bounced off the table by a powerful shot. Drying is just molecules getting progressively jostled out of the liquid until they're all gone. The same thing happens with the molecules in a solid too but, since they're bound even more tightly, it happens more slowly. A vacuum speeds the process up dramatically, because there are no air molecules to ricochet the 'jumpers' back down, and so any that do break free can make good their escape.

Freeze drying is very useful for food preservation. The food is first frozen to prevent the food from spoiling, and it is then dried slowly in a vacuum for several days, with carefully controlled heat, to gently remove the water without affecting the food structure. ***LV***

ALAMY, SHUTTERSTOCK, GETTY IMAGES ILLUSTRATIONS: PETE LAWRENCE

NATURE'S WEIRDEST CREATURES...

BIRD-DROPPING SPIDER

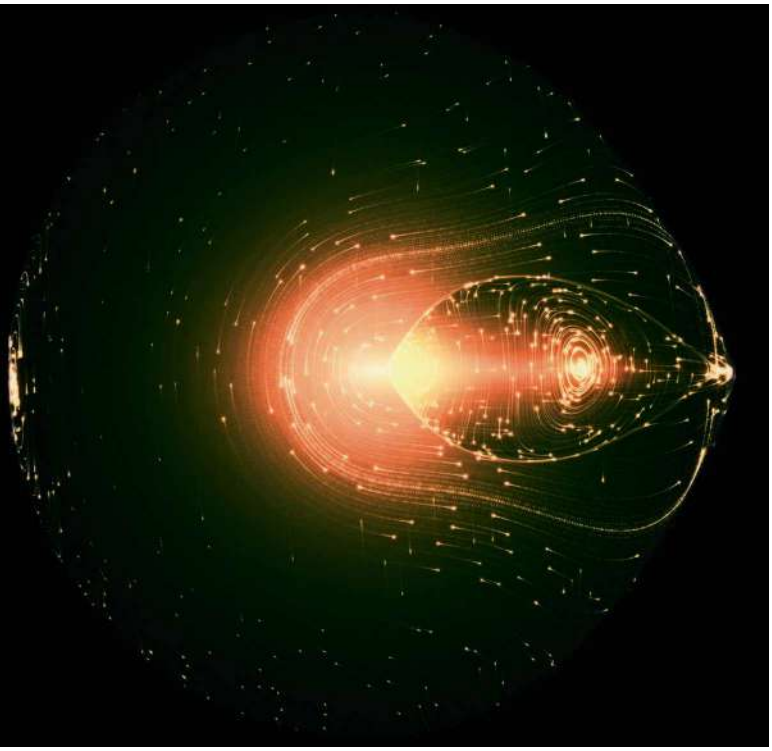
In ordinary circumstances, it's not good to look like a pile of poo, but for the bird-dropping spider, *Celaenia excavata*, this evolutionary strategy is a lifesaver.

Found in Australia and New Zealand, the medium-sized arachnid has a chunky, triangular body daubed in splodges of brown, black and white. During the day, when it rests, it folds its legs up against its body, making it appear, to all the world, like a freshly deposited bird dropping. This camouflage is so convincing that birds often overlook this potential food source, leaving the faecal fraudster to brazenly style it out on the surface of a leaf or twig.

After sunset, however, the bird-dropping spider takes its mimicry skills to another level to help it catch its prey. The spider dangles upside-down from a tree with its front legs outstretched, and releases a chemical scent that mimics the airborne sex pheromone emifl ed by female lawn armyworm moths to afl ract mates. Hapless male moths looking for love fly towards the rogue odour and are then grabbed by the spider and devoured, or wrapped in silk and saved for later. *HP*

HANNAH GRAHAM, BATH

COULD YOU PROTECT ASTRONAUTS FROM COSMIC RADIATION BY CREATING A MAGNETIC FIELD AROUND THEIR SPACESHIP?



Dangerous energetic particles emitted by the Sun are mostly deflected by the Earth's protective magnetic bubble, called the magnetosphere, or absorbed by the atmosphere. Astronauts outside this relatively safe environment, on the Moon or Mars, for example, would require some other means of protection if they are to avoid the harmful effects of this radiation. It has been demonstrated that a 1 Tesla magnet (similar to the strength of magnets in an MRI machine) would be able to provide a magnetic shield about 100-200m across. This is technically feasible and would be capable of deflecting the majority of harmful solar particles. ***AG***

CROWDSCIENCE

Every week on BBC World Service, *CrowdScience* answers listeners' questions on life, Earth and the Universe. Tune in every Friday evening on BBC World Service, or catch up online at **bbcworldservice.com/crowdscience**

WHICH IS BETTER: OPTIMISM OR PESSIMISM?

Optimism and pessimism are fundamental traits of the human brain. With optimism, there's the 'Just World' hypothesis, an ingrained assumption that the world is fair and that good actions will lead to good outcomes, and vice versa for bad ones. There's also the 'fading affect bias', where memories for negative emotional experiences fade faster than positive ones. And then there's the 'planning fallacy', a cognitive quirk where we constantly underestimate how long a task (such as driving to the airport) will take, regardless of how often we've done it before.

These three traits alone show that optimism infuses our perception of past, present, and future. The same goes for pessimism, however. While our memories may skew positive, our emotion and attention systems show a negativity bias – we give more weight to and spend more time dwelling on negative experiences. And while the human brain has the impressive ability to create complex simulations of events and scenarios, much of this is used for negative or worst-case scenarios, and taboo thinking. Ever stood on a cliff or high building and thought "What if I jump?" for no discernible reason? Now you know why This is how our brain works. We need optimism to keep us motivated, to compel us to perform actions, and reassure us that we have control over our own lives. And we need pessimism to keep us grounded, wary of risks and dangers, to make us recognise limits and restrictions.

A complete absence of optimism is often seen in people with severe cases of depression and anxiety, while zero pessimism can lead to unrealistic expectations, victim-blaming and harmful emotional suppression.

Exactly which is more important in any given situation will vary considerably, but it's impossible to deny that both optimism and pessimism are essential parts of our psyche. ***DB***

ALAMY X2, GETTY IMAGES ILLUSTRATION: DANIEL BRIGHT

HOW DOES A GROUND SOURCE HEAT PUMP WORK?

Ground source heat pumps harness the heat energy stored naturally in the ground and concentrate it to provide energy etticient, year-round heating and hot water for your home.

1 SUBTERRANEAN HEAT

Sunlight warms the ground and this heat percolates down through the subsoil. The process is slow enough that the daily and seasonal weather fluctuations are evened out. Even in winter, the temperature is a constant 10°C two metres below the surface.

2 ABSORB THE HEAT

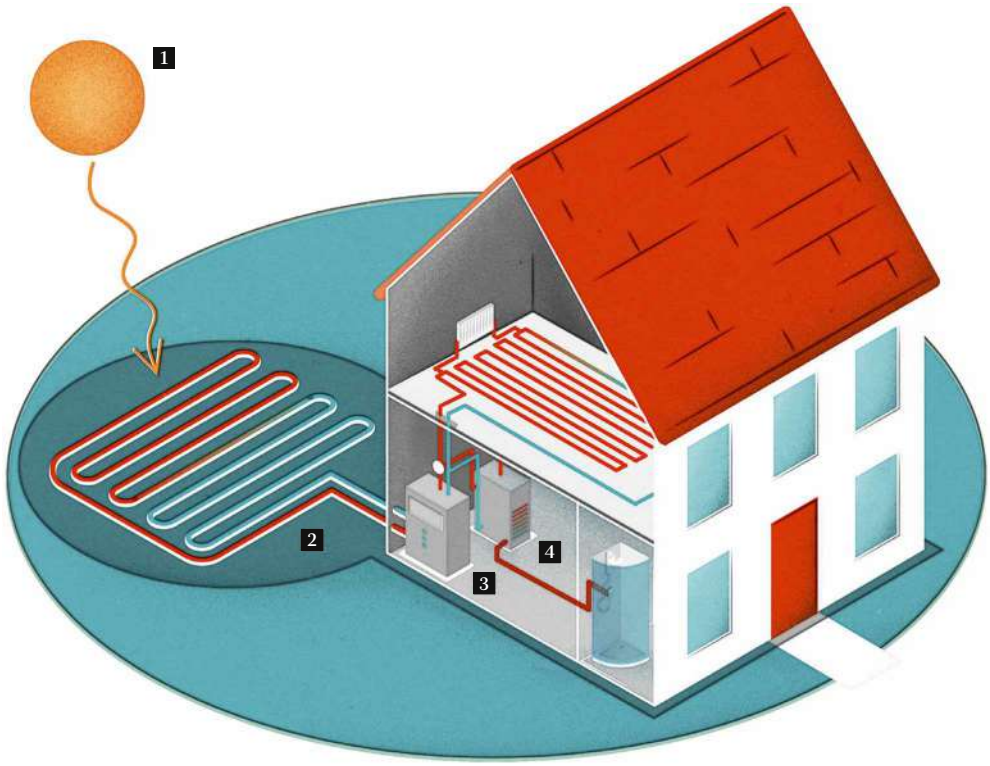
Water and antifreeze are pumped through underground pipes in a closed loop to the heat exchanger located in the house. The water is warmed up along the way by the enormous reservoir of stored heat in the ground.

3 TRANSFER AND CIRCULATE THE HEAT

The heat exchanger uses the warm water to evaporate a more volatile fluid – usually the same fluid that's used as fridge coolant. The evaporated vapour is then compressed using an electric pump to raise its temperature high enough to heat the water in the property's inner heating loop.

4 REDUCE ENERGY USE AND STAY WARM

The pumping and compressing uses less than a third as much electricity as heating the water directly because most of the energy comes from the ground heat. The inner loop runs at a lower temperature than gas central heating though, so it's best used with underfloor heating or larger, low-temperature radiators. ***LV***



ROY YOUNG, LEEDS

WOULD EARTH BE ANY DIFFERENT IF IT SPUN THE OTHER WAY?

An Earth spinning in the opposite direction would have very different atmospheric and ocean currents. Although the global mean temperature would remain almost the same, the major ocean currents would switch from the Atlantic to the Pacific, changing the planet's climate drastically. The result would be about a quarter of all deserts in Africa and Eurasia disappearing (being replaced by woodland or grassland). The Amazon basin would become an arid wasteland, the Russian steppes would be positively balmy, northwestern Europe would suffer extremely harsh winters, and the Atlantic sea ice would have a much greater southern extent. Although survivable, you might not recognise your particular spot on the planet! ***AG***

DEAR DOCTOR...

HEALTH QUESTIONS DEALT WITH BY *SCIENCE FOCUS* EXPERTS

I'M PATHETIC! WHY DO I HAVE SUCH A LOW PAIN THRESHOLD COMPARED TO MY SISTER?

To answer this question, we need to ask several more. The first of which is: do you mean pain 'threshold', or pain 'tolerance'? Because they're different things.

Your pain threshold is the point where a sensation (temperature, pressure, spiciness of food and so on) crosses a line, going from being innocuous to causing you to experience actual pain. The extent to which you can withstand and endure the pain you're experiencing, while continuing to function, is your pain tolerance.

It could be that your sister has a lower pain threshold than you, but is hence more used to dealing with it, so has a relatively higher tolerance. Also, is your sister older or younger? And are you her sister, or her brother? Pain thresholds and tolerance are things where age, sex and other factors have a significant impact. For instance, it's regularly assumed that women have much higher pain tolerance than men, because they can experience childbirth. But research shows that, while women often report experiencing more pain than men, their pain tolerance increases dramatically during pregnancy and labour, due to the many significant physiological and hormonal changes they undergo as a result of the process.

Overall, someone's ability to experience, process and endure pain is determined by many, constantly shifting, factors. It's hard to say how many of these apply to your sister. But there's no guarantee that they always will. ***DB***

Baculum of a ringed seal. Now you know

NEIL JONES, LONDON

WHY DON'T HUMANS HAVE A BACULUM (A PENIS BONE)?

The baculum is a free-floating bone used to improve the rigidity of the penis during penetrative sex. Bats, bears, dogs, otters, pandas and walruses all have a baculum, but humans don't. Since our primate ancestors had one, we must have lost ours through evolution.

A baculum allows the owner to copulate for extended periods, making it harder for another male to sneak in and add his sperm to the mix. This is less important for humans, since we evolved a more monogamous mating strategy around 1.9 million years ago. For humans, shorter and more frequent sex is preferable to a single marathon session and so the baculum is unnecessary. ***LV***

ALICE THOMPSON, LIVERPOOL

WHY DOES CHEMO CAUSE YOUR HAIR TO GROW BACK DIFFERENTLY?

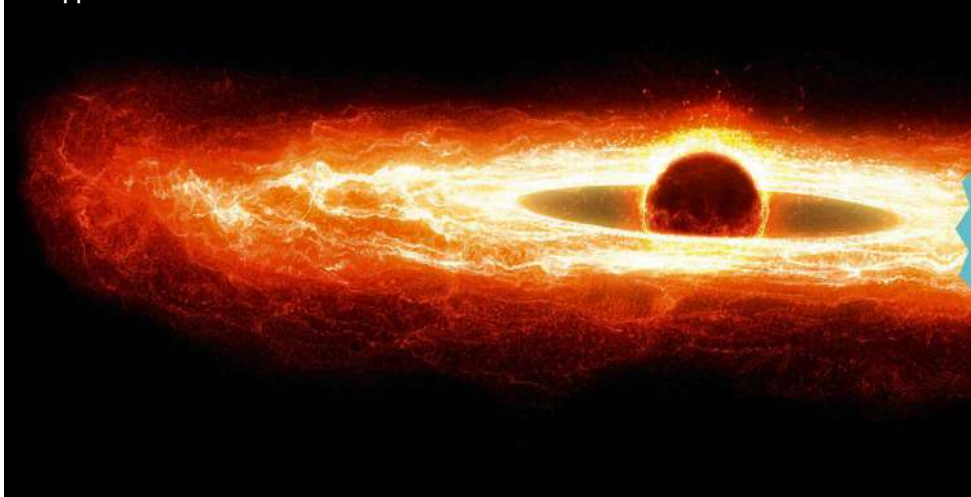
When hair begins to grow back after chemotherapy, it will probably be slightly different in texture or colour to start with. Some people report having 'chemo curls', where the new hair is curlier than it was before chemo. This might be because the shape of the hair follicle can alter during treatment, and become twisted. Over time, once the hair has grown a few centimetres, most people find that their hair starts to take on a familiar texture. For most people, their hair will fully recover within 12 months. ***NM***

QUESTION OF THE MONTH

STEPHEN BROWN, HUDDERSFIELD

WHY DO WE THINK THERE ARE BLACK HOLES IN GALAXY CENTRES AND NOT SUPERMASSIVE SUNS?

The evidence for supermassive black holes (SMBHs) at the centres of most (if not all) galaxies, is both direct and indirect. Observations of 'quasars' – the extremely bright cores of distant galaxies – shows that they're releasing up to a trillion times the energy of a typical star, all within a volume no bigger than the Solar System. The only mechanism that can explain this huge energy release is the conversion of gravitational energy into light by a SMBH. Any other kind of object, such as massive stars, simply cannot produce the observed amount of energy. Plus, it appears that stars of more than a few hundred solar masses are unlikely to form because radiation pressure prevents collapse of the 'proto-stellar' cloud. Even if extremely massive stars did form, their lifetimes would be too short (a few million years) to account for the number of quasars seen in the Universe. However, the best direct evidence for SMBHs in galaxy cores comes from observations of the motions of stars in the vicinity of the central object. Their extremely high orbital velocities can only be explained if the central object is both extremely compact and extremely massive, in other words, a supermassive black hole. ***AG***



WINNER

The winner of next issue's *Question Of The Month* wins a pair of **Marshall Minor III wireless earphones**, worth £119.99. Marshall's wireless earphones deliver the deep, characterful sound the amp manufacturer is famous for. And you can enjoy 25 hours of playback with the help of the Marshall-branded portable charging case. **marshallheadphones.com**

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

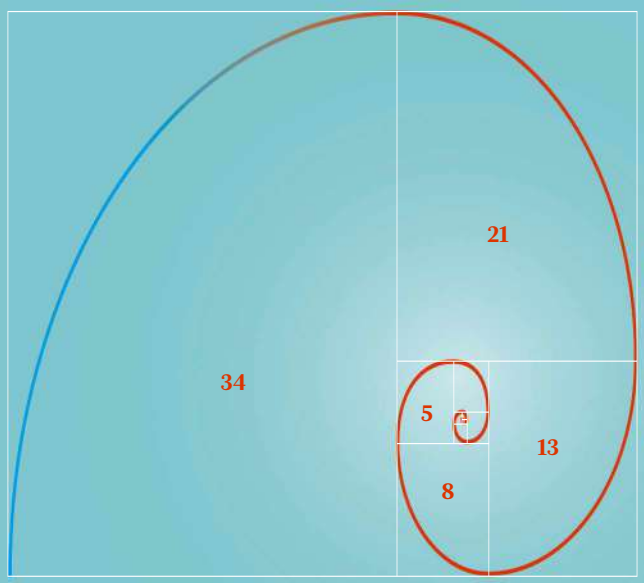
SCIENCE PHOTO LIBRARY, GETTY IMAGES, ALAMY ILLUSTRATIONS: DAN BRIGHT

THE EXPLAINER

THE FIBONACCI SEQUENCE

WHAT IS THE FIBONACCI SEQUENCE?

1, 1, 2, 3, 5, 8, 13, 21... The Fibonacci sequence. Every number in the sequence is generated by adding together the two previous numbers. So the next Fibonacci number is 13 + 21 = 34. They are the simplest example of a recursive sequence where each number is generated by an equation in the previous numbers in the sequence. Hidden inside this sequence is another important number in mathematics: the golden ratio. Denoted by the Greek letter phi, it is a number like pi that has an infinite decimal expansion with no patterns. It starts phi = 1.61803... It's defined as the ratio of a rectangle of dimensions A x B where the ratio A/B is equal to (A + B)/A. This is regarded by many artists as the perfect proportion for a canvas. If you divide a number in the Fibonacci sequence by the previous number in the sequence (for example, 5/3) then this fraction gets closer and closer to the golden ratio as you take larger and larger Fibonacci numbers. There's a formula for the Fibonacci numbers involving the golden ratio that avoids having to calculate all the previous numbers. There are still mysteries about these numbers. For example, are there infinitely many Fibonacci numbers that are also prime numbers? Like 2, 3, 5 and 13. We only know 51 Fibonacci primes, but could there be an infinite amount?



WHY ARE THEY SO IMPORTANT?

They are nature's favourite numbers. You find them all over the natural world. Count the number of petals on a flower and often it's a Fibonacci number. (If it isn't, that means a petal has fallen off your flower, which is how mathematicians get around exceptions). Cut open a fruit and often you'll find a star shape with a Fibonacci number of arms. A banana has a three-pointed star, an apple a five-pointed star, a persimmon an eight-pointed star. Count the cells on a pineapple and you'll find several Fibonacci numbers. The seeds in a sunflower also exploit Fibonacci numbers to pack efficiently. Fibonacci explained that these numbers are at the heart of how things grow in the natural world. Nature uses what it has grown so far to make the next move. If you take squares whose dimensions correspond to the Fibonacci numbers, then it's possible to arrange them in an expanding rectangle, which explains how they help grow things and why they give rise to spirals. Fibonacci also explained how these numbers keep track of the population growth of rabbits. If a pair of rabbits take a month to mature before it can give birth to a new pair of rabbits, how many pairs of rabbits will there be each month? The answer is in the Fibonacci sequence.

ALAMY, GETTY IMAGES X3

WHO WAS FIBONACCI?

The numbers are named after a 13th-Century Italian mathematician from Pisa. Fibonacci wrote about these numbers in a hugely influential book called *Liber Abaci,* published in 1202. His book was meant as an aid to new ways of doing computation and explains the power of the new Hindu Arabic numerals. He learnt about these new numbers while travelling in North Africa. In Europe, they were still using Roman numerals and the abacus to do calculations. But using the abacus required skill and expertise. It meant that calculation wasn't something that was available to the common citizen. Rather than using clumsy Roman numerals, Fibonacci explained how the Indians exploited the numbers 1 to 9 together with the revolutionary new concept of 0 to express numbers efficiently using the place number system. Fibonacci's book gave the common citizen access to calculation and the ability to record those calculations. This is why the establishment initially tried to ban the incoming numerals from the East. His book is responsible for kick-starting mathematics in Europe during the medieval period. It's in the book *Liber Abaci* that he introduces the sequence of numbers that now bear his name.

WAS FIBONACCI THE FIRST TO DISCOVER THESE NUMBERS?

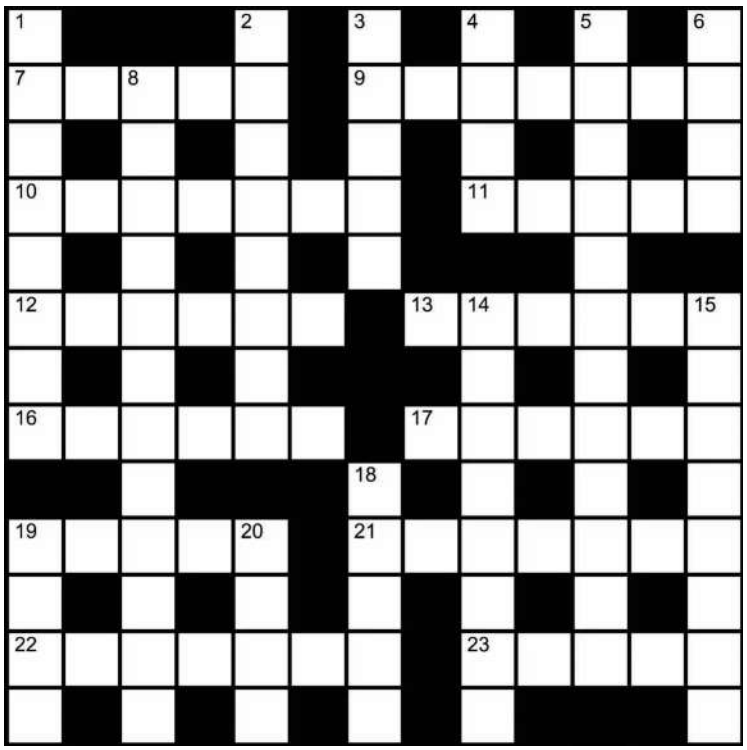
No! It turns out that these numbers should really be named after Indian poets and musicians, who discovered them centuries before Fibonacci. Rather than nature, it was understanding rhythm in music and poetry that was the secret to their discovery. How many different rhythms can you make on a drum if you combine long and short beats? For example, if a long beat is twice a short beat then here are the number of rhythms you can make of length four: SHORT-SHORT-SHORT-SHORT, LONG-SHORT-SHORT, SHORT-LONG-SHORT, SHORT-SHORT-LONG, LONG-LONG. A total of five different rhythms. A Fibonacci number! If you wanted to make rhythms of length five then you can take the three rhythms of length three and add a LONG beat to them, or take the five rhythms of length four and add a SHORT beat to them. So there are eight rhythms of length five. The number of rhythms grows according to the Fibonacci rule. Many modern musicians have enjoyed using the Fibonacci numbers in their work. For example, Debussy uses them in his piece *La Mer* as does Bartok in his *Music For Strings, Percussion And Celesta*. There's even a new form of poetry, called a Fib, where each line has syllables corresponding to the Fibonacci sequence.

by MARCUS DU SAUTOY

Marcus du Sautoy is the Simonyi Professor for the Public Understanding of Science at the University of Oxford and author of Thinking Better: The Art Of The Shortcut *(£13.99, Fourth Estate).*

CROSSWORD

PENCILS AT THE READY!



ACROSS

7 Temp, eccentric and unknown, used glass (5)
9 Washing – French articles – no longer wet (7)
10 Mission – include a large composition (7)
11 Small nuisance, getting a lot of land (5)
12 Endless flowers at home for old money (6)
13 Writer catching cold turned it into a setting agent (6)
16 Darrel's off to the store (6)
17 Identify an index, say (6)
19 Sulked, getting a motorcycle (5)
21 A few lines on how to behave in pub (3,4)
22 Church items broken by drugs dealer (7)
23 Inventor of strange tales (5)

DOWN

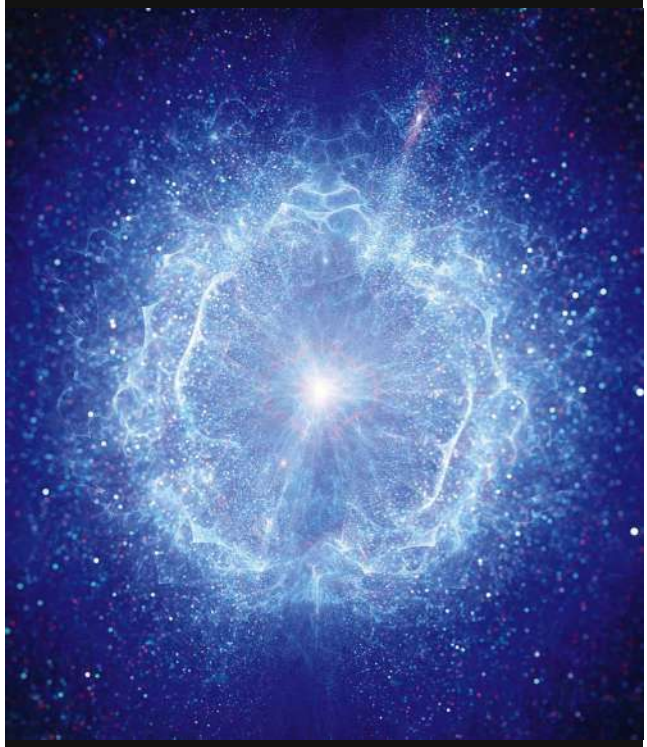
1 Firm clue about being forgiving (8)
2 Diet many reconsidered a very exciting thing (8)
3 Depressed by singular style of music (5)
4 Drawback – society has courage (4)
5 Beneficial, as Uganda vote goes wrong (12)
6 Fancy Anthony acquiring some colour (4)
8 Snappy character – confused hag or prophet? (12)
14 Move to space next to one fireplace (8)
15 Courage to talk of chemical weapon (5,3)
18 Sailor had food to cool off (5)
19 Spice used as a weapon (4)
20 Swim around river, finding weed (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

NEXT ISSUE

COSMIC MEGA EXPLOSIONS



GETTY IMAGES

PLUS

AIR TAXIS

Several companies are building air taxis to make our journeys faster and cleaner. How soon will these vehicles grace our skies?

GREEN PLANET

David Attenborough's latest series looks at life on Earth, from the perspective of plants.

ON SALE 20 JANUARY

SF

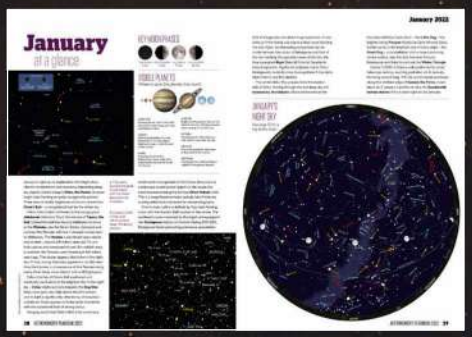
FROM THE MAKERS OF BBC Sky at Night MAGAZINE

The Astronomer's Yearbook 2022

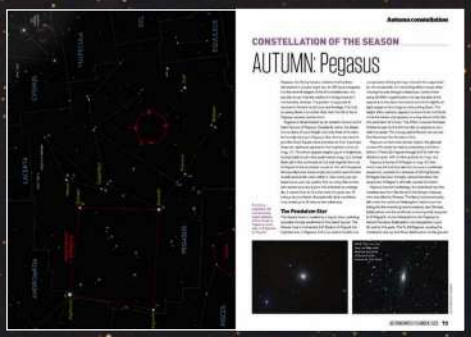
Get ready to explore the best stargazing sights in the night sky over the next 12 months with *The Astronomer's Yearbook 2022*. This indispensable guide from *BBC Sky at Night Magazine* contains a year of stargazing tips, how-to guides and equipment details. Monthly star charts guide you to the best views in 2022 and will help you keep track of the eclipses, oppositions, occultations and meteor showers coming up. With expert advice on the constellations of each season, challenging objects to track down and more, you'll be ready for all the top astronomical events in 2022.

PLUS Receive FREE P&P on this special edition

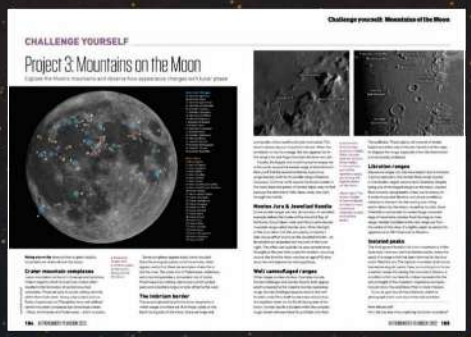
Chris Bramley,
Editor, *BBC Sky at Night Magazine*



Our month-by-month guide and detailed star charts reveal what to look for and when, from stars and planets to Moon phases and more.



Get to know the stand-out constellations of each season, as we highlight their brightest targets and how to best observe them.



Develop your skills with our Challenge Yourself projects, whether it's observing lunar mountain ranges or classifying galaxies.

ORDER YOUR COPY TODAY

visit: www.buysubscriptions.com/Yearbook2022

Alternatively call 03330 162138† and quote 'The Astronomer's Yearbook 2022'

† UK calls will cost the same as other standard fixed line numbers (starting 01 or 02) and are included as part of any inclusive or free minutes allowances (if offered by your phone tariff). Outside of free call packages call charges from mobile phones will cost between 3p and 55p per minute. Lines are open Mon to Fri 9am–5pm.*Free delivery on UK orders only.
Prices including postage are: £9.99 for all UK residents, £12.99 for Europe and £13.49 for the Rest of World.All orders are subject to availability. Please allow up to 21 days for delivery.

TERRY HANCOCK

POPCORN SCIENCE

Could you be cryogenically frozen?

It's a task harder than doing the Kessel Run in less than 12 parsecs

by STEPHEN KELLY

In *Star Wars: The Empire Strikes Back*, Han Solo achieves every billionaire's wildest dream by being frozen alive in cryogenic stasis – proof, as if it was needed, that he really is the coolest guy in the galaxy. Solo is frozen as an experiment by Darth Vader and Boba Fett (the latter returning to our screens in *The Book Of Boba Fett*, streaming on Disney+ from 28 December) to see if he would survive the 'carbon freezing' process. Fortunately, he does. But according to Gary Bryant, a physics professor at RMIT University in Melbourne, Australia, Solo wouldn't have been so lucky in reality.

"There's no evidence of any cryoprotectant being injected into his body and there's no human cell you can freeze without adding cryoprotectant first," he says. This is because when the human body (which is mostly water) is frozen, ice crystals form inside cells, which destroys them. Cryoprotectant prevents that, but there's a catch. For even if Solo did have his bodily fluids replaced with cryoprotectant, it would have killed him anyway – because the cocktail of chemicals in cryoprotectant is lethally toxic. "You'd just be left with the skeleton and the dead cells, like the skin," says Bryant. "The brain certainly wouldn't survive."

This is why, according to Bryant, the idea of cryogenically freezing a live human being is "a long way from possible." In the real world, cryopreservation is mainly used in fields such as fertility, to preserve eggs and sperm, and in scientific research, where cells such as cancer cells are frozen in storage. But as far as the human body is concerned, the number of cells that can be frozen is limited.

"There are well over 200 types of cells in the human body, and we can freeze fewer than 10," says Bryant. "Even then, we must freeze them under different conditions. So to freeze red blood cells we have to use very high concentrations of cryoprotectant. We must also freeze them quickly, because the cells respond fast to changes in their environment. White blood cells, we have to freeze slowly and use smaller amounts of cryoprotectant."

All of this means that freezing the cells in a human body, where they're all jumbled together, is hugely impractical.

There are companies that offer to cryogenically freeze people, but only after they're dead. In 2016, for instance, a 14-year-old British cancer patient won a court case to have her body cryogenically frozen by an American firm called the Cryonics Institute. The logic – or hope – in cases like these is that one day science will reach a point where the frozen bodies can be revived and cured.

There's a school of thought that this will be achieved through advancements in nanobot technology, with tiny robots reconstructing the body and brain. But it's fair to say that Bryant is not convinced.

"We'd have to actually understand the brain enough to be able to reconstruct it," he says. "We don't have any idea what the brain does. We don't know how memories or knowledge are stored. We don't know how people's reactions are stored. The brain is what makes you *you*, and that's what you want to preserve."

Bryant thinks that companies like the Cryonics Institute are exploiting vulnerable people's fear of death. "People are being given false hope," he says. "There's absolutely no way of those bodies being recovered. It's not just about preservation anymore. They're also saying, 'Okay, now we've got to bring people back from the dead.'" And even if Han Solo did like the odds, "preservation and reanimation are two wholly different impossibilities." **SF**

VERDICT
It doesn't matter how strongly the Force might run through your veins, nobody is going to survive being frozen alive.

by **STEPHEN KELLY** *(@StephenPKelly)*
Stephen is a culture and science writer, specialising in television and film.

ILLUSTRATIONS: ADAM GALE MAIN ILLUSTRATION: CHRISTINA KALLI

In the woods, not every conversation starts with a Tweet...

Technology innovation is helping save Earth's natural habitats and ecosystems. Bio-acoustic monitoring, combined with AI and cloud technology, is allowing conservationists to better understand and protect endangered species in real-time, like never before.

The Mammal Society, Rainforest Connection and Huawei UK are teaming up to help conserve the indigenous and rare red squirrel species in the UK.

Get involved with
The Mammal Society
www.mammal.org.uk

Photography by Dani Connor | @DaniConnorWild

Mammal Society

RAINFOREST CONNECTION

HUAWEI

TECH 4ALL

Learn more about
Huawei TECH4ALL